## ABRIEF HISTORYOF TIME 13 1143 00936 6239

THE UPDATED
AND EXPANDED
TENTH
ANNIVERSARY
EDITION



## STEPHEN HAWKING



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A brief history of time
Updated and expanded
tenth anniversary ed. WESTSIDE

#### ALSO BY STEPHEN HAWKING

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# A BRIEF HISTORY OF TIME

UPDATED AND EXPANDED
TENTH ANNIVERSARY EDITION

STEPHEN HAWKING



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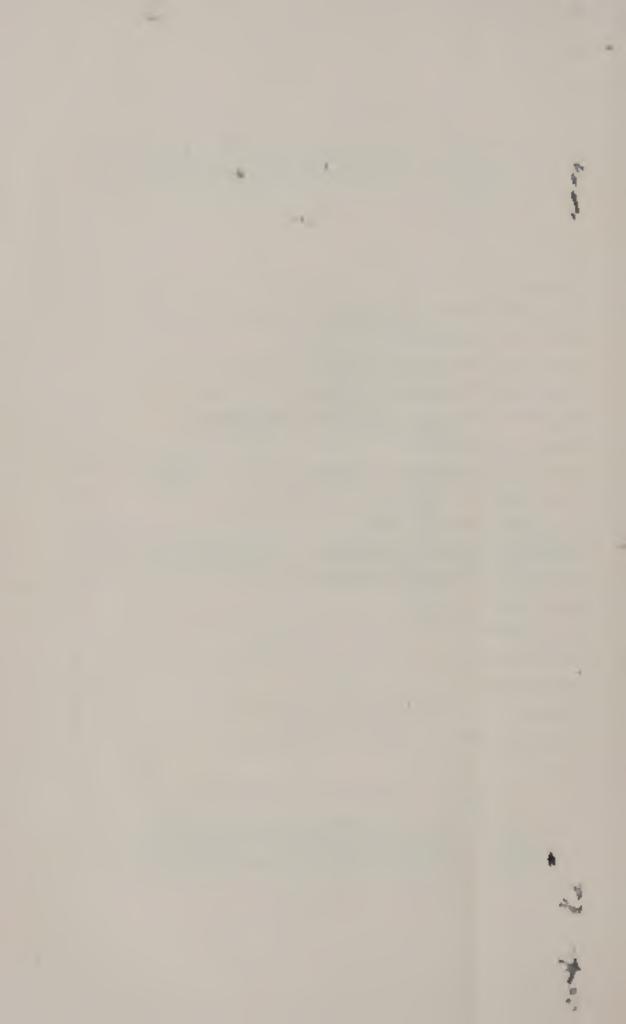
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#### FOREWORD

I didn't write a foreword to the original edition of A Brief History of Time. That was done by Carl Sagan. Instead, I wrote a short piece titled "Acknowledgments" in which I was advised to thank everyone. Some of the foundations that had given me support weren't too pleased to have been mentioned, however, because it led to a great increase in applications.

I don't think anyone, my publishers, my agent, or myself, expected the book to do anything like as well as it did. It was in the London Sunday Times best-seller list for 237 weeks, longer than any other book (apparently, the Bible and Shakespeare aren't counted). It has been translated into something like forty languages and has sold about one copy for every 750 men, women, and children in the world. As Nathan Myhrvold of Microsoft (a former post-doc of mine) remarked: I have sold more books on physics than Madonna has on sex.

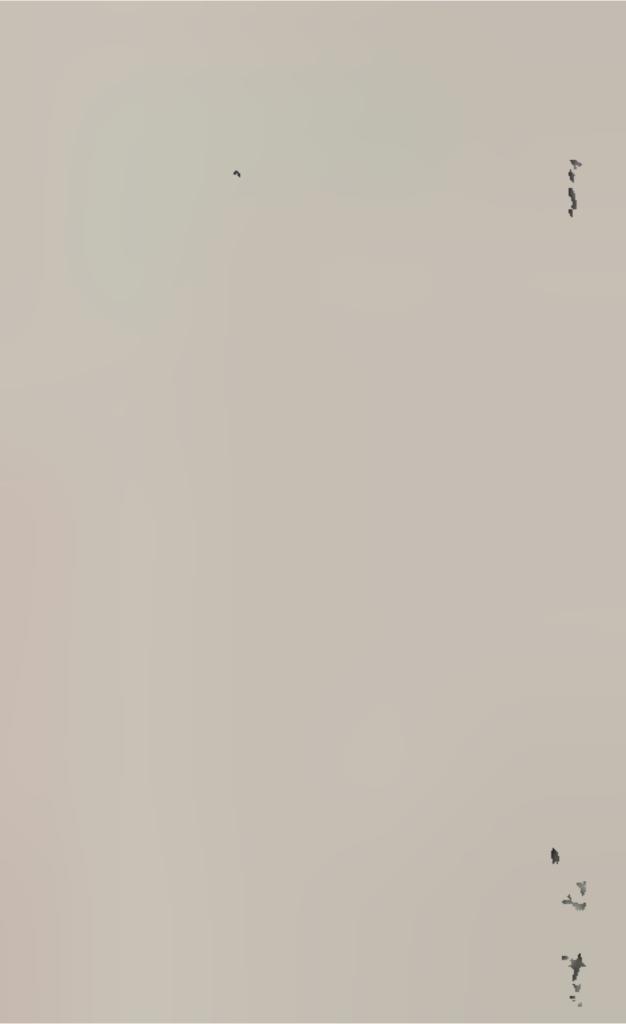
The success of A Brief History indicates that there is widespread interest in the big questions like; Where did we come from? And why is the universe the way it is? I have taken the opportunity to update the book and include new theoretical and observational results obtained since the book was first published (on April Fools' Day, 1988). I have included a new chapter on wormholes and time travel. Einstein's General Theory of Relativity seems to offer the possibility that we could create and maintain wormholes, little tubes that connect different regions of space-time. If so, we might be able to use them for rapid travel around the galaxy or travel back in time. Of course, we have not seen anyone from the future (or have we?) but I discuss a possible explanation for this.

I also describe the progress that has been made recently in finding "dualities" or correspondences between apparently different
theories of physics. These correspondences are a strong indication
that there is a complete unified theory of physics, but they also
suggest that it may not be possible to express this theory in a single
fundamental formulation. Instead, we may have to use different
reflections of the underlying theory in different situations. It might be
like our being unable to represent the surface of the earth on a single
map and having to use different maps in different regions. This
would be a revolution in our view of the unification of the laws of
science but it would not change the most important point: that the
universe is governed by a set of rational laws that we can discover and
understand.

On the observational side, by far the most important development has been the measurement of fluctuations in the cosmic microwave background radiation by COBE (the Cosmic Background Explorer satellite) and other collaborations. These fluctuations are the finger-prints of creation, tiny initial irregularities in the otherwise smooth and uniform early universe that later grew into galaxies, stars, and all the structures we see around us. Their form agrees with the predictions of the proposal that the universe has no boundaries or edges in the imaginary time direction; but further observations will be necessary to distinguish this proposal from other possible explanations for

the fluctuations in the lackground. However, within tew verts we should know whether we can be excluding velocities and we see that so on the ety self-contained and we have majorited to

Stephen Hawking



### OUR PICTURE OF THE UNIVERSE

A well-known street streamers as a was bertrand Russon and have a public ecture on strending. He describes how the earth orbits around the sun and how he seed a transparaty. At the end of the ecture, a little not like at the pack of the room got plands of little and the transparation of the nack of agriculturense. The access stransparation and the mack of agriculturense. The access stransparation of the room got plands appear to the temporation. The access stransparation of the room got plands appear to the temporation of the mack of a griculturense. The access stransparation of the room got plands appear to the feet of the mack of a griculturense. The access stransparation of the room got plants support to the room got plands and the stransparation of the way down!"

Most people would find the corner four an verse as an infinite over of cornsession or once loss but why do we find we know to terr. Whit is we know a marche an orse and his consecution of Whore a line is verse come from and where is a great fixed on a rescharge accepting and a so, with a punctibefore their. What is the native of time? With the encounter can end? Con we go back to the P. Recent are akthroughts in places, made pressible in part by

fant is a new technic ignes, suggest answers to some of Tese long standing questions. Someday these answers may seem as ibvorus in us as the earth orbiting the sun or perhaps as redictions as a liver of terroises. Only time, whatever the times below if expenditures as a liver of

As using ago as 34. By the Greek phi is other Ar store in his look. On the Heavens, was able to put thrward two good arguinen's for believing that the earth was a munit's here talker than a thirplate. First, he real zed that eclipses at the mach were caused by the earth caming between the sun and the moon. The eart is shallow on the moon was a vays round which was I be true in yo the earth was spherica. If he earth had been a ff disk the shadow would have been elong ited and elliptical unless, he eclipse always occurred at a time when the san was firectly under the center of the class. Second, the Greeks knew form their trive's that the North Stat a peared hower in the sky when viewed in the south than it is donmore northerly regions. Since the North Star Les over the North Pole it a pears to be a recely above an observer at the North Pole, ar to someone hoking from the equalor, it appears to lie last at he horizon From the difference in the prairie post on of the North Stor in Figure and Greece. Aristotle even quoted an estimate that the distance around the earth was 400 and statia last not known exactly what tength a stall, in was, but I may have been bout 20 yap s. which would make Aristotics esample about twice the correctly accepted figure. The Greeks even had a chird a go nent that the earth must be round, for why else uses one first see the sails of a shipcoming over the barron, and only later see the bol?

Aristotle thought the earth was statularly and that the sun, the moon, the planets, and the stars moved in circular orbits about the earth. He believed this because he felt, for mystical reasons, that the earth was the center of the universe, and that circular manch was the most perfect. This lea was elaborated by Projemy in the second century AD in the my mete cosmological model. The earth stoud at a center surrounced twenty to spheres hat carried the moon, the sunthe stars and the file planets know that the time. Moreovy, Venus.

As restricted and Saturn I great True presentence was never than the extreme to the entering and the entering and the entering parts in the sky. The outcomes sphere extreed he socks on these stars which a ways stay in the same positions returned to each at the which rotate together across he sky. What ay severe he has a time which rotate together across he sky. What ay severe he has a time which rotate together across he sky.

If the emy similar presented a reasonably accurate system for predicting the positions of heal enly bodies in the sky. By an order to predict these positions correctly. Pedemy has to mike an assumption that the month discover a path to issue of messioning that mode as close to the earth is at other mass. A notice of an internet moon ought sometimes to appear which is higher a transfer areas in order to the discover recognized his illustrative mass his in ideal was generally although our matters who also has adopted by he Christian concerns the picture of the universe triat alignment with a single prediction of the discoverse triat alignment with a concern as the picture of the universe triat alignment with a contract to the discovery

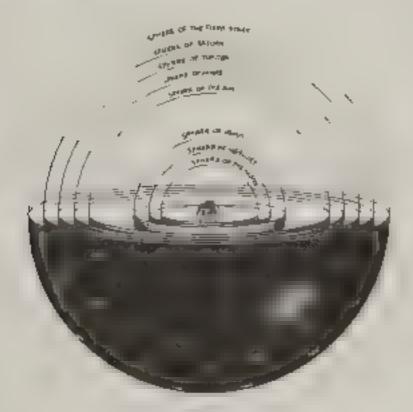


FIGURE 11

a variage that it of total it come mass do the sphere of fixed stars for heaven and heat.

As more mode, it were was proposed in 1514 by a Polish priest No as Capernicus (At hist per and for ear of being orange) heret by his church Copern curve related his missel that y heads. His dea was that the sin was stat mary at the lenter and that the earth and the plane's moved in circular orbits around the sun. Nearly a cent ry passed before this dealy is lake seroully Then two istronomics he derman John, es Keller, and the talan Galler Collicial is arted publicity to a priorith in operation theory coapite die fact that he makes no died did not quite much the mess ascreed The death brow to the Ar storelland to email theory come in Italy In hat year ( a lee star ou observing the hight sky with a telescope which has problem are in Wien he mixed a the panel lepter Garren and that it was accompanied by several small sate lites in machs that orbited around it. This implies in the very borg is food have our it breet, around the earth as Aris it and fix emy had throught it was, of course or I possible to believe but the earth was scausinary at the center. Fithe universe and had he mixing it will ter moved on extremely complicated has surround the east giving the a meanance that they exhited Jupiter However Copernious's theory was merb's impter. At the same time, Johannes Kepler had modified Copernial as theory, suggesting that the planets mixed not an oricles but a eligible and all se suite ingatesta oces. The president proposifinally matched the observations.

As for a Kepler was concerned ell prival orbits were mere y an allow exportiers including replanant one at that because ourses were clearly less pertent than in less Handgards were did most by account that of prival orbits by the observations well he could not reconcile them with his lead that the planets were like to contithe sun as ingress corees. An explanation was provided only much their in 168 when Sir Island New in published his Philosophiae Naturalis. Principle Mathematical probability he most important single work effective.



the ry thow no session terms pace and three out he also developed the complicates made matter as the complicates made matter as the considered those more has a land of Newton postulates a law of universal gravitation according to which the body in the process was a tracted mand every other body by a force him is a surfager, he have interestive the body estands to closer they was a to each other himself is same or as the cause a objects to full to the ground. The story that Newton was inspired by an apple butting his head as a most certainly apocrypha. A Newton himself ever sail was that the role of gravity came. In this she had an a memphasist most, and the role of gravity came. In this she had an a memphasist most, and the role of gravity came. In this she had an a memphasist most, and the role of gravity came. In this she had an a memphasist most, and the role of gravity came. In this she had a not memphasist most, and the role of gravity came. In this she had a not memphasist most, and the role of gravity came.

The Capern can model go rich of Polesia's cesestial spheres, and with them the against the converse had a natural boundary. Since "fixed stars did not a lear to change their post and aper into a rotation across the sky caused by the eight spiriting on its axis, it became natural in supmose that the fixed stars were object spike surs in but very much farther away.

to show hat according his law gravity causes he more to move in the promoter are another earth and causes the earth and the line is

tails low ellowest purhs around the sen-

Newton realized has a continue to his the try of grants the stars some formaticach sther some seemed here out a not remain essentially moniess. Worse they intially liteget end some point it a elect a try to Rachard Ben bey another ending think in whis day. Newton argued that his what indeed action for there were any a finite number of storal distributed, over a finite regard of space. But he reasoned that his mother has a there were an infinite number of stars, east noted more or less an formly over infinite space. This would not a pien because there would not be any central point for them to fault to.

This argument is the same with pitfalls that you can encounter it is by shout into a linear office universe every point can be segment as the center persise every point has in infinite in a near of

stars meach wile for The correct approach, it will realized only much later, is a consider the finite situation an which the stars all fail in on each other, and then to ask how things charge if one aids more stars mugh yuniformly distributed of the emissing of According to Newton's awith extrastars with I make to ill terence at a ito the original lines on average so the stars would fall in just as fast. We can as I is many stars as well ke but they will still always collapse in in them serves. We now know it is impossible to have an in the static mode of the converse in which gravity is always appraising

It is a repesting reflect in on the general contact of thought before the twent eth century that no one had suggested that the universe was expanding or contracting I was generally accepted that either the inverse had existed forever man, achonging state, or that it had been created at a finite time in the past more or tess as we observe it inday. In partiths may have been due to people's tendency to be level in eternal rings, as well as the comfort they found in the thought that even hough they may grow old and the, the universe is eternal and an changing

From those who realized that Newton's theory of gravity showed har the universe. In any he static did not think to suggest that it might be expanding line can, her alternitied to most ty the theory by

At g the gray fat anal force repulsive at very large distances. This did not significantly affect their productions of the main and of the planets, but it a lower late the eastribution of stars to remain in each horizon on which the artractive forces between nearby stars balanced by he repulsive forces from those that were farther away. However, we now be tove such an equilibrium would be unstable if the stars in some region got only slightly nearer each other, the attractive index between hem would become stronger at 1 leminate over the repulsive cross so that the stars would commute to all toward each other who the other time, if the class got a bit farther away from each other the repulsive forces would dominate mo drive them for her apart.

Viother direction to an infinite static an verse is normally ascribed



the Carman phonomer Her min bers who wrote about this there n 14.3 a feet with a same a property of New entrolling the problem and the Chers of the say at each he first the tip places ble inguments against a little in however the install be wicely notes. The difficulty is that man infinite tark is serve hear viewery ne of sight wour end in the surface of a stee Thus one would expect that the whole sky who libe as bright is he sun even it night. a hers contering me to a that chiant i or tot or a re won I be lander by a story to by a terve of and as H wever that happine at a sterve inglisher would ventually heat up onto it glas labrica y as he stars. The only was of a congression of so electric while of the night sky she il be as ingle as a smale right sun would be to assume hat the stors had in their an ing one in but has turned on it some the air in the past in the case the absorbing major is gli me have heared appet in he light cone search stars in a to a vertice reached is An that in as as to be question is what can have as sed the siles if here is not not the first place

The beginning of the opterse has a course men secased to place and the I wish a horizon. Mush to then the injects of early and appearant the I wish a horizon. Mush to the past the organization reach a legion of another the best and the past the organization for the test and the past the organization as a treatment of the another as a treatment of the another as a treatment of the another and the conserve of the another and the conserve of the another and the conserve of the another and the another and the another and the another are the past of the another and the another are the past of the another and the another another and the another another another and the another another another and the another another and the another another another another another and the another another

last fee Age about MaNN as , which is when archaecing state cost to civilization ready began )

Aristotic, and mistigat the other Greek philosophers in the ciper hand lid not be the atea of a creation because it smokes that much of distinct tervent or. They believed therefore, that the homan race and the world around it had existed, and we have staffer or. The ancients had a ready considered the anglament about progress described above, and answere latitudes as a fact that there had been period infloods in other I sasters that repeated a see the human race right back it the began angla of civil zation.

The questions of whether the imperse of Ta hegin on a nic and whether it is tim ted in space were later extensively examined by the is using the manual Kant in his pronumental and lery observe Work Critique of Pure Keason, pub shed in 1781. He called these ques ions antinom es that sucception is it as or pure reason recause de exitled here were educily compelling arguments for the exity the thus so that the an verse had a beginning, and the antithes so that it had existed prever His argumen for the thesis was that if he in verse a linot have a legan and there would be an induce lerious of time but the any event, which he considered absord. The algune hater the aniely esis was that if the an verse had a beginning, there would be an ir finite per at all time before it so why should the an verse begin it any one parties are time. In fact, his cases too both the tases and the antithesis are really the same argument. They are bill hibased it is unspoken assumption that time continues back torever whether is not rise werse had existed forever. As we shall see, the concept of time has an meaning before the majoring of the universe. This was first pointed out by St. Augustine. When asked "What die Gas co before he creams the universe. Augustine code riter y "He was preparing Hell or pulppie who asked such questions. Instead the said that time was a property of the applierse that God created and that time I of exist before the heart una of the inverse

When most people believe in an essent ally static and and longing



As the case and fates epopolitical along the action of the depth of the depth of the depth of the action of the depth of the case of the c

the less abservar ons suggested flat there was a line of the below has give hear converse was though has a last a reverse the estimate themso he awardscene and berefore labs by the present of three word break lown It here were expression for here this rate he has a ne liner a feet what happens at the present tap The inject stemper can be ignored because it would have be three at a consequences Operation say that in charactery on nglature ig long in telsense title meninges som passion bette de les la sociales. rendered to telephone a processory forces of local has been and less presentable from nearing the in the abration at i and is some orbit garha bas to be uniposed by some or operation. The in the fire is that physical necessity or thegoring trivial may hat Concern I be an corse at socially any a continuous the at arthur I the animerse seam to here is he pressed the why there halt take a logic ring. One can't st. may be then creater he appearse a their stant he big has a new atorious a stign a way as to make to make thought are has been by borg. by the life meaning essites may be a was created before he had being Americancing an arrase a less in president ere in his toris I was to see when he migh have carry lear his jul-

In river talk about the number of his universe on the solar green it as a has whether this a big on og it a new him have to be clear ability what a scientific heart is I was it we the sold will be view but a beary si is a more of the process of a restricted or of a and a set of the less of the language trees in the monde, to observations that we ske like sise by nour not sould be snot have a vother roll v is hatever hat might mean. A theory is a good throny if it so ships two requirements it must accurately leserned a right save their dors crathe rasis to mide I do not a live lower transport notes and t must make different and a about the example to have the form is For example, Aristotic he level I happen a case hears that every hing was made not of four eligible earth air hire and eller this was at pechagt built in ake well tegretat to first either hand Newton's theory or gray by sushaso of a fine or some of mach hibraties a tracte leach oth risith a reinning was reint. to a quantity and a less mass a mersely proper on to the empty of the distance be with them he has the members of the sun the muon and the poor so a high regres it destitutes

Any physical theory is divining to such a finite sence that the life is you can never project in a control of the animal many they he results in experiments agree with soft of the vinite interpretation of the time of time of the time of time

At least that a what is a spose to be in the series of all a question becompetened to the person whose tricks of the observation for practice what often be in a sight of the second form.



the services on the provious throny Forexame, ery cource district in the planet Moreury revealed is a leaffer as leaved to mot an first productions of November a terror organity historia go and being of relativity predicted as globy tere in an anti-head while was seen with New most theory. The act that Einstein productions matched while was seen with New theory. However, we sell us to most him, and of the new theory. However, we sell us to work him, for a practical particles because the difference new to a specific along the action of general relativity is very small in the situations that we notice that the production of the new to be a situations that we notice that the productions the action of the situations that we notice that the production of the new to be a situations that we notice that the production of the new to be a situations that we notice that the production of the new to be the production of the new to be a situation of the new to be a situat

The even of goal of some is to provide a single trainer that describes he wastern as the wastern action of the wastern at the solution of the provide here are the wastern to that how the uncertainty solution places in the converse is kelatany attributed as the converse physical converse who wastern and attribute the provide physical converted who only the cost formence point that so me should be in the cost former to be regard here the cost of the converted who only the cost partition regard here to be and standard to an above as a major for the cost of the standard provide here is a solution of the cost of the

at turns continue and like the season a febre to describe the universe of one go loss of we break and, rist emisped base a pent of her of partial theorems. He had these with a herales districted districted districted as a finite continue to the effect of their particles at representing the by a time sets naments at may be the other particular to be an organized for the arms of the effect of the particular to the same and a continue to the arms of the effect of the particular to the effect of the fact of the particular to the effect of the fact of the f

parts of the extrement isolation. Nevertheless, it is estable the way that we have made progress in the past. The classic example again is the Newtonian theory of grains which to be as that the gravitational force between two last established on a control number associated with each last is at associated with each last in a mass but is of nerve a hour penetral of which he had example of the single and the part at an affect the single are the rightest

The visige tists lescribe he haverse in crims of two basic art a theories the general theory of refut its and quantum mechanis. They are the great intellectual achievements of he are har of his centry. The general theory of return ty celebrate the are grantly and the large so le saract to core o reerse it sat as the structure on searcs four only a few miles to as a ge as a malion not make in m I on with twenty our zeros after it in his their zerot the observe able of corse Quant mechanics on he other nar wals with phenomena ar exit mely shall so less so is a blanch or and Liopth of an inch University, however, here two thiories are knowled the reconstruction with each other they come which be carfor the state many offices are proyected, or live a protheme rich situates is the search of a new theory has some acquired them. with in a intermit errory of gravity. We do no wet have such an incryand we may still be a long was from having one but we up a ready kn w many of the principles had a most have. And wished see in later chapters, that we already know a fact are out the title ore to to succeeding theory of gravity must make

Now a me exect a businessess not arbitrary by as giverned by definite and you are fately have a combine the parea theory is a will a scribe everything in the at verse But there is a fundamenta parallix in the search for such a complete a relations. The deas about so on a theorem we are a so all beings who are free an observe the mixture is we want and a crawling oil reductions from which as the



In such a scheme to is reasonable a suppose to the implifier gross ever closer award he was that govern our anywerse. Yet there really is a complete an first hearty who it also because the our entering of our actions. And so the timesty set fine a determine the our came of our search that a And who should be determine that we come a the right case as any from the contact of Might that expansion whell determine that we can the wrong canclast the right of the contact of the wrong canclast the right of the contact of the wrong canclast the contact of the con

The my answer that can give to this progen is used on Dorwins principle in raise ec in The sea sithal many population isc removed by their sums there will be a real ons in the general motor all and uppringing has different a vicinish se. These sterenors all mean that some indicals are be terrapie to an others a crass the ght cone usions about the world around them and sact a core loggy. These he side is we be more likely to survive and reprostice he so their paiern of brisk in a things will either in reade Is has ertainly been true to the past has what we call into ligence and soje the fisch ery have conveyed a survival advantage. It is not so that there is said the case ours, in the isolates have well desired as a land even fithey len't help were any editheery has not make much difference to our chances of survival. However, provided the universe has eviden in a region way we might extent that the reasoning an ites the natural selection is given as whall be valid also may the are of a complete to beary and so we are not lead us to the wrong conclusions.

Because the partial theories the side areas y have are soften to he accurate presse acos in all but he most extreme situations the search for the ait may bear y of he a overse seems I, head to just y an practice groups. It is worth many bough that simily arguer is could have been used good both remay by and chapted inchants, as here theories assegned as both release energy and the microe earlies revoluted. The factories has proceed to implete an heat theory, herefore may not of the sum of the species of may need even afternoon to style B reversing the dawn the lization people.

have not been distrest to see events as unconnected and mexplicable. They have croved an understanding of the underlying order to the world. Today we still years to know why we are here and where we came from Plumon ty's deepest desire for knowledge is justification of the continuous gaples. And our goal is nothing less than a complete accompany of the converse we live in

#### SPACE AND TIME

Our present ideas about the in his let hold excite back to that a Newton Before them people are avoid Arist at a who said that the natural state of a body was in he at rest and that a new mile if driven by a force or impulse. It followed that a heavy body should a faster than a light one, because it should have a greater plus intoward the earth.

The Aristote an tradition also held that one could work our allege laws that govern the universe by pure though, it was not necessary of book by observation. So no one anti, Galley hothered to see whether book es of different weight of 1 of fact fall at 1 ferent species. It is said that Galdeo demonstrated that Aristotic's belief was also by drop the weights from the carning tower of P said The story is aim ist certainly an rue, but Galleo did do something equivalent in rolled balls of different weights down a smooth slope. The standor is such larty that of heavy bodies failing vertically built as easier to observe because the speeds are smiller. Galleo's measurements indicated that each body increased its speed all the same rale, no matter what is weight thor

example if you be good, had an a stope that Ir ps by one meter for every on meters you go along, he bell will be traveling down the same at a speed of along one meter per second after one second over meters per second after two seconds, one so on towe in heavy the ball of the success a lead weight who, it all after han a feather but that is drive occause a feather is slowed hown in air resistance. If the arms two bodies that done have much air resistance, such as two. Terent lead weights, they fall a the same rate. On the moon where there is no air to slow things down, the astronal to David R. Scott per affect he feather and lead weight experime than and that indeed they Jack the ground at the same time.

Creations measurements were used by Newton as the last and his aws at mattern. In Gay eos experiments, as a bridge to lear down the slepe it was a ways acted on by the same force as weight, and the effect was to make a constantly speed up. This showed the the reeffect addice salways to change the specule, abock rather than 1 st to set it moving, as was previously hought It is the total when ever a builty similable, on by any line it will keep in a stong mastraight one at the same speed. This dealwas first staied explicitly in Newton's Principia Mathematica, published in [187] and is known as Newton's best ass. Wha has pensitive bing where there i we action it signers by Newton a section on The states had the bully will a city are or change its speed, at a rate that is propor sonal to the force. For example the acceleration is twice as great if the force is twice as great. The loceless too as also smaller the greater life mass can quantity of master, of the body of the same time acting in a non-yed twice, he mass will produce hall the acre eration. A fair ar examine symmetried by a can the more powerful the engine the greater the acceleration by the heas or the rar, he simular the acceleration for the same eight # Inauthority his away finist in Newton iscovered law to accombe the force of graits, which states that every body at racts every or A body with a force that is proper a nall done mass, each body. Thus ghe torce be ween twill bodies would be twice as strong it one of the boldies



that they a had to these then I This is the you ment expected to the test to the test to the volume of the proposed of the test to the test to the test which we do attract broke B with the original force. The state of talknown is when a such the two re the original force. And is say one of the burnes had a see the mass, and the other had treed these terms, then the test expects be sixthese as a ring since can be a see to year bookes to be the same rate a body from come weight will have twice the one of gravity principle committee we see the pass Act of log to Newton's second law western of effects will exactly cancer each other so the accident in which the resame thall cases.

Newton since you was relieved by the arrhes for he bodies, the some error error. New make as of gravity says that he gravity home at actions a start sessed y me plaster that of is more start, had the distance T is take ready after or as in the earth the more, and he planets with great accuracy. If he has were that he gravity then a fittered in of a star went cown faster or increased more rapidly with a wance, he orbits of he planets would not be raptoral hey want in her sport in the sub-order part of her

The ong I ference he ween the ideas of Aristotic halfhose of the color of Newton is that Aristotic be eved in a priferred state of rest which any body would take optimizers or the by some force or impulse an particular, he hought that the early was tires. But is, we from Newton's taws that here is a via que scancard of rest. One contemporary well say har body is was at rest and body is was at rest and body is was at rest and body is was a rest and body it was mentioned with respect to body it or has the Brows a rest and body it was mening from example, one service and for a anomaly it was at rest and the sum indicate the court was at rest as I the energy was mening is of a carrier or har the train was at rest as I the energy was mening is of a carrier or har the train was at rest as I the energy was mening is of a carrier or har the train was at rest as I the energy was mening is of a more type from the real of the carrier or experiments with maying makes in the run, all Newton's laws was a fine that the har nothers, and the Prog Fong on the rain, one would fine that the

had obeyed Newton's away is like a half in a table by the track. So here is no way to be living or this time a rithe earth to at is nicology

The lack of about the standard of rest meant that one courd not be true he whicher two even's that took place and becent times of carred in the same position to space. For example, suppose or r.P. ng. Pong has no the train onto essentially in Town when it is given the able two with the same spot one second apoint. Town when it he made the two bounces would seem to take place about forty meters apart breaks the arm now of have traveled that far down the track between the positions. The minex's ence of absolute rest therefore meant that one case out give a color and about to position in space as Answere had be leved. The positions of ven's ar fithe lastances between the now the ferent for a person in the train and one con the rack and there is no a ferent for a person in the train and one con the rack and there is no a like the some operations position to the others.

New nowas ary women by this aix of largete position or about espace as the about a because a dimoral, and with his lead in the circ Cool In their he refused to accept lack of a book relaptive continuous to was more of the his laws life was severely enticized for his irrational healef by many people may not any his Bishop Berkeley and loss than who believed that a material impects his space and time are an illusion. When the firmous Dr. Johnson was told of Berkeley's open in, he circled in refuse it has large stone.

Both Ar a of each Newton believed in a school of the Sithly believed historic club, nambigs busy measure her terval of time between we exents, and that this time would be the sime whoever measured it provided they used a good clock. Time was at inpletely separate from any in ependent of space. This is what most peripe who disable to the trends mesensely on Helicery we have that to change has ideas about space and time. Although our pagarently communicated in the ventures work we have the original time. Although our pagarently communicated in the ventures work we have the property dominated the ventures of the venture of the venture of the venture work it all for things move good in the specie of the venture work it all for things move good in the page to the page to the page.



The a than glo travels at a fire but they a ghi speed was his e a cred n e bigt a Danish astronomer (Ne Christensen Roemer He were combattle times tach the morans of a serie peace ato has been all upiter were not a enly spaced as included aspect if he THOS WE THUN Hapert die nistant raie. As he earth and Jupiter or hold at son the coaste between the mouther Moenter nothered the ecliments a lap term of Histoppe red aterms I have were remaining the regularithment was necessarily that can be mains to killing to the swhen we were an eroway has measured ents fer arte and the strice of the east to n lepter were were remote create trate no se his value for the specific that was 4) tell mates per scenne containe to the magern value of 186 illi6. tex ser ar en Neverthen is. Rue ser's ach exement in not niv tranger to got rives dafined sheet by and a mean righthat specificans remark by coming is too cleven years to be a tens publication of Principle Mathematical

A proportion of the proposal of the control of the work with physicist innest lerk. Maxwell succeeded to a syring to part the homes that a protother had been used to discover the forces the circuit of the part than Maxwells end on spredicted had there a border was take a studionics. The combine Telectric hagners the land that the selection of the control of the discovered had been a point of the wave eight of here waves take distance between one wave trest and the next is a meter of mare, they are what we have call radio waves. Shorter where gifts are known as it is maked to the centimeter. Visible the same in the acceptance of the part of the same and the selections of the control of the same and the same and

Make a sthrough precietes to the court plan waves should trave at a corrain back specified. Newthern the light of the search associated as a fixed specified as a fixed specified as a fixed specified was the creative relative to the dispersion of the creative and the creative an

It was harefure suggested that there was a subscance called the "e her that was present everywhere e en in empty is alse Taght was as show it trave abrough the other as son as waves travel through a rand their sine I statust therefore be relaive to the ciner Different observers, may be relative to the either would see light coming toward them all furent speeds, but light's speed relative to the other will I remain fixed in particular as the earth was moving through the ether on its orbit roughlithe sun the speed of ign measured in hear rection. t the earth's not in a rough the other when we were nin ng asward the source I the ight should be higher han the speed of ight act ghr angies to that mot on (when we are not moving toward the source) an 887 A here Miche son, who later became the first American to receive the Nobel Prize for possess and Foward Money carried but a very careful experiment at the Case School of Applied Science in Coveland. They impored he speed of light in the cirection of the earth's metion with that at right angles to the eart is motion. To their great scriptise they found they were exactly the same!

Between 1887 and 195 there were several attempts most in 1,124 by the Durch in visits. Headrik Lorentz, to explain the result of the Microscon Mortey experit nert to retrins of objects contricting and collects showing lown when they moved through the ether. However, in a famous paper in 1950, he here conknown early in the Swiss latent office. A best Einstein, perited out that the whole local of an other was unaccessary providing make a few weeks later by a railing French mathematician. Hence there is a few weeks later by a railing French mathematician. Hence the are fabstein along ments were closer to physics than those of Poincare who regarded this problem as mathematica. However, is usually given the credit of the new theory but Poincare is remembered by having its name attached to an important harmoid it.

The fundamental postulate of the meory of relain ty as it was called was that he laws of science should be the same for all free yourself globservers, or matter what their speed. This was true their New of slowers of mission, but now the idea was extended a include



Messe term and the perdotting that observers digit mess rehe sink speed at light to matter a worst they are many This simply that has some remarkable consequences. Perhaps the hest s own are the equit conce dimassions on the simple with the see as fare many in the end owhere his mergy, mas must une a s the special fight and he as a could give seed taster than he sixes of light Hes se fire econstence of metas and mais, the e cray which and rect has due to come top as addition in many if it wirds and make the root to access to spece. I have been s my real significant or three similar ig a species use of the species of ger Firegand at a percent the specified ger in their smiss s my 15 percent tore han normal ways it percent of he med t igh twish he mor than wee as noting miss As an ign approaches respect ghors hass mass error more quick your takes more and one here's especial tup forth of Ir after as never re chi he speed if ghi because is then is miss would have her me that e are by the equivariate to small energy twin I have tiking infinite anicunt of thereby te government. For this reason and or a other as there experiented by relativity to minimum species a over he the special ghalf he hight another was sthat he can arrange mass, can move at the speed of ght

An equally removes the desired and the laway with way that revolution may be out the space and the line how all a pulse of light is sent from one place of mother, infecting observers we be agree in the time that the minimum to the since the winds of the majority will not a way agent in he with the global control street when it is not a sense of the special of the table is just the district that the control has taken in the reservoir as who is a source of the inspecial store the ghealth as the other himself, and expects that agree on how astilly time is I exist in a sense the not agree on the assumes the light his indicate that it was a sense that it is a support to the light his received a fact that is also as a sense the light his received to not agree with a support the light his sense the observers to not agree.

on Joseph who gits spear a schitter de agree en la atom word, le beory diels dry acon indicate described of in la appeared that each absence must have als avainmentaire. It may second absence as a summer and the test all access rathers by different absences was lost necessarily given.

Each observer or and lose to or a say where any when her not nothing the same to deal and all procedures as a first of he pulsa is reflected back at the event and the observer neasures, he time at which he reserves the cells. The me of he event is ben said to be the time has will between when he mise was sen and the line wien he reflect on was rule son book the an in the even is half the time raisen for this round trip in tiplice by the specific agree Ar event this se se a some log that likes pincriat a single print in space a la specified protection to an shower night which san example of 1 Space for diagram and all as record to observers whip are miving related to each other will associate that may me positions of the and close a Nopartic or observers that to be to are any tire correct than the tier districts, but il, he neasure in a are realled. You wastrain an acre on precise a what time and position in all or mercera lissign to in the fire with the knows the other observer's relative velocity.

Nowalians we use just his not in the master that reside casely herapse velocity and measure are the action of his desired the peterns he action that he has been as more than as in the other hands as a more than the reason to the paractual not interest his corresponds to the interest in actions his amarks in a participant and another than bar kept. For a legacy two case use a more consume to the unit of ength as his legacy two case use a more consume to the unit of ength as his legacy two case use a more consume to the unit of ength as his legacy two case use a more consume to a the state of the action of the hard the hard the hard that have the means of relations as the how whether is not in terms of a remaining the special light, soft that lows are in a light to every a nearly of master participation as seed by the hard the same as leading to the hard the same as leading to the covery and the special light to the co



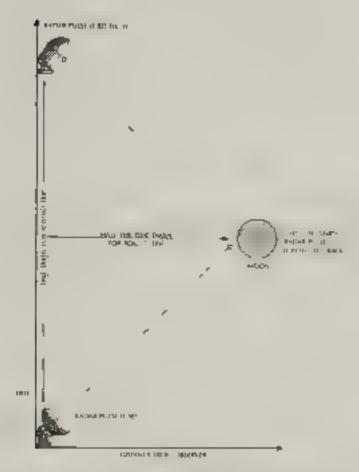


FIGURE 2.1 Time is measured vertically, and the distance from the observer is measured birranotally. The observer's path brough space and time is shown as the vertical on the left. The paths of light rays to and from the event are the diagonal ones.

There is no need to introduce the leads and riser, whose mose is anyway cannot be detected as the Michelson Mercy experiment showed. The theory of relativity does however, once us to change fundamentally our ideas of space and time. We must nice to at time is not completely separate from and the energy of space, but is combined with the form an object called space time.

It is a matter of common experience that one can describe the position of a position to a space by three numbers, it is indicated. For instance, one can say that a point in a room is seried electrons one will bree feet from another and five feet above the floor of the count specify that a point was at a certain and the another gitted and a certain relighbourses sealest. One is free to use any three so table coordinates.

shows the post of the source o

And one same bag the britains are all the first name of a second at a price of the Solven and the second section of a second sec

specifying is not in the new construction of the section of the section of the message of the section of the message of the section of the end of the section of the record message of the section of the message of the section of the

so generally use diagrams nicht hier acreases consist all me die spit die mensions sish own horizon. Vi The order two spatial hours are agained or sometimes and of their is noticated by terspit the These are lattled spatial nicht diagrams. Kit gill die example in Fig. 2.2 time as incascred appeared in versional the diagrams of hierarchy in a first the single Alph Centum is measured to receive a high hierarchy in the single Alph Centum is measured to receive a high and single space time are shown as the single all near or the chanding the analysis of the diagram. Alpha of the diagram Alpha of the from the sun to lows the alignmal and analysis.

As we have seen. Maswells, place on the tracks space of light should be the same what conthe space of the sound moderns has been continued to see intermeasurements at follows aromeths, had to use I ght use introduced an apart color time at a portion in some

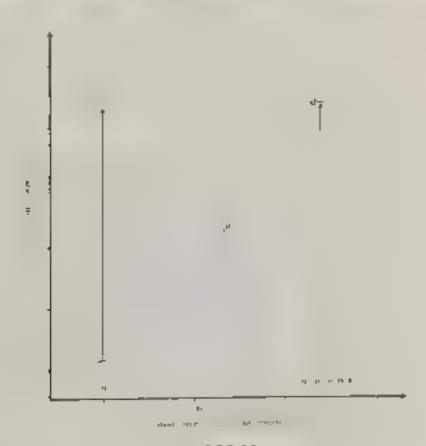
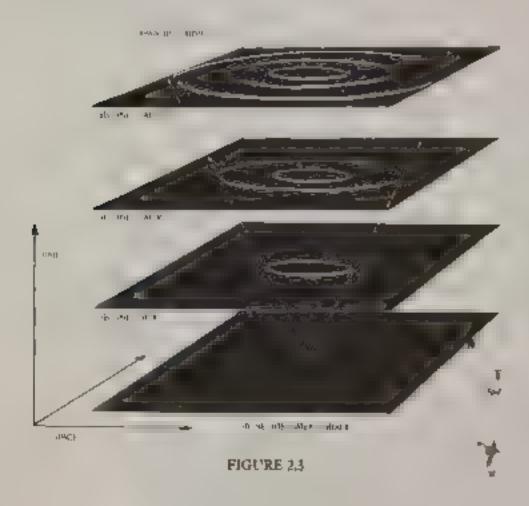


FIGURE 2.2

space then as a meight service will spread out as a sphere of tight whose size inclosured are helpful detected the special of the source. A left one millionth of a second the light will have spread on to our mossification with a radius of solimeters after two million that is second the radius will be 60° meters, and so could be not be the hippost of a spread out on the solid agent of when a solid is the other hippost of a spread out on the solid gets of get as time goes on the other the expanding one of noness will mark out a cone whose the other the expanding one of noness will mark out a cone whose the state has place and time at which the stone has a more different cone in the four dimensional space time. This cone is called the fature given me state even a firm a near in piletic light is abte to reach the given event (Fig. 2.4).



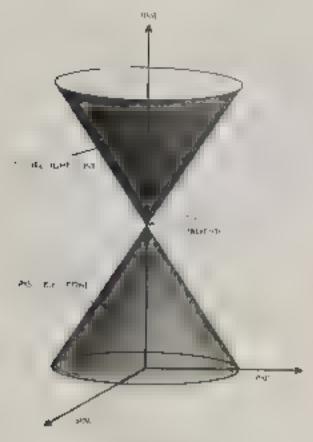


FIGURE 24.

Given an event P one can car do the other events of each verse not three classes. Those events that can be reached from the event P of a particle at wave traveling at or below the speed of light are said to be the future of P. They will be with not on the expanding sphere of aght on trea from the event P. Thus they will be within it in the fature ghr rone of P in the space time Lagrant. Only events to the latture of P can be affected by what happens at P because nothing can trave faster than light.

Similarly the past of Pican be defined as the self-all events from which it is possible to reach the event Pitravel agia or below the speed of light. It is thus the seriet events that can offect what happens it Pithe events had do not be in the following past of Piare sail and events elsewhere of Pitrig a 5. What happens at such events can trei her affect not be a fected by what in piers at Pitro example if the sail

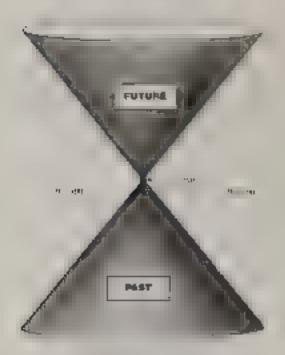
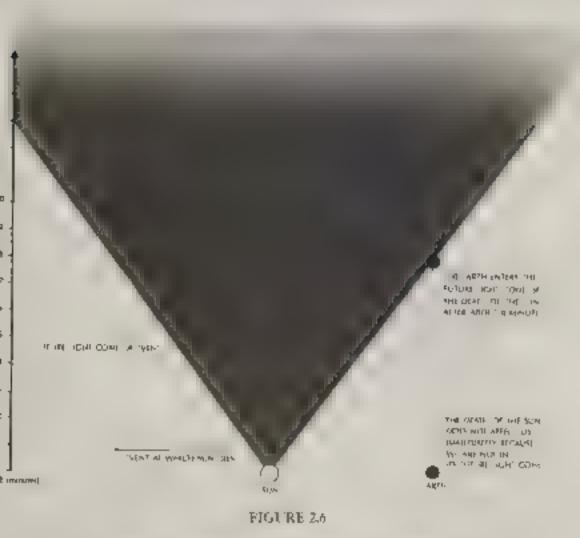


FIGURE 25

carthat he present are because they will die in he considered the exertination present are because they will die in he considered the exertinate of the exertinate of the after eight or nates the area trakes, ght to reach us from the single reight or nates the area of the attractions from the single events in earth, the he attracts of the event of which is an agent at he larly, we allow the own what is her tening a the notice of an area away in the unit erse the ight that we see from a stanting assess of them in the affects age and in the case of the most distant object that we have seen, the light left some right the assed in the vertex age. Thus, when we look at the analytise we are seeing it as it was in the past.

I the neglects gravitational effects as Boster and Property I, in 405 one has whit is called the special theory of the and a Edge every ventur space time we may construct a light cone the sector alignment and ance the special aght is the same at every even and in every direction, altithe light ones we see dentication in the same direction affine



heory also a sustination high control elementary aght. This mean has the path of all poble effort agree space and are a list be represented by a methat has with a the got one ateo has enten to the 2.7. The special theory of relations was very successful in explaining that the special of light pipears he some to a conservery is shown by the Macilian. A previously the form to a conservery is shown by the Macilian. A previously also to be sheed of aght. However it was not as stellow that the Newtonian theory if grainly which said to a macilian to a total or an with a first that lepen and in the distance have a rate of I as meant that if in missible to the objects have a rate of I as meant that if in missible to a synthetic has the gray a small effects show in the walls a first to be synthesis.

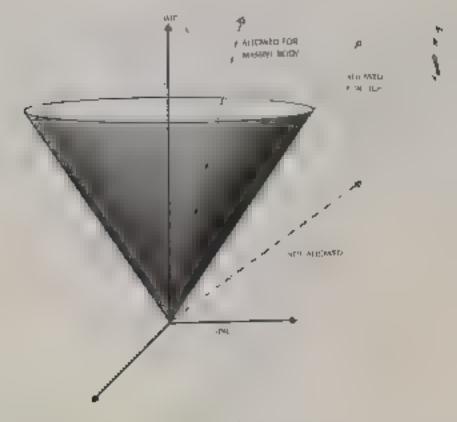


FIGURE 17

instead at at or below the speed of light, as the special theory of relativity required Einstein made in inherical a succession afternoon between 1908 and 19 a rathogola heary or gray ty that was consistent with special relativity. Finally in 1915, he proposed what we now call the general theory of relativity.

Emstein made the revolutionary suggestion hat growty is not a torce like other forces, but is no insequence of the total hat space time is not flar, as had been previously assumed in scarved, or warped," by the fistribution of mass and energy in it had est ke the earth are not made to move on curved orbits by inferce cared grayity instead they often he nearest thing to a straight path in a curved space, which is called a goodes of A geodesic is the shortest or longest) path between two northy parts. For example, the surface of the earth is a two dimensional curved space. A geodesic on the earth is called a great careir, and is the shortest route between two points. Fig. 2.8. Againetic of and is the shortest route between two points.

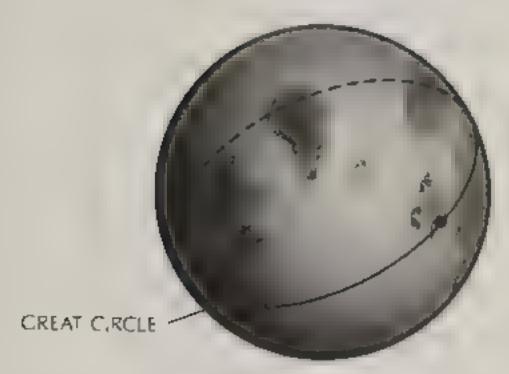


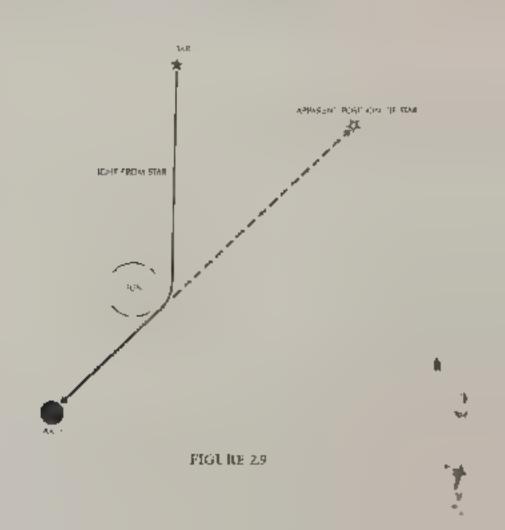
FIGURE 2.8

geodesic is the showest path between any two a spaces 1 is a termine an air and naviga or will elicited in the fly along an general relative, but beginned always follow strate the estimate for impossional space air elicited most along curved paths in our three-dimensional space. (This is rather take watching an airplane flying over 1 years in Although it follows a straight incompliced measure space, its solative mass a curved path on the two-simensional ground.)

The mass of the san curves space meet a mach a war that a magh the earth follows a straight path in four aimens and space time appears to as to move along a circular orbit in three. I mensional space In fact, the orbits of the plane's precise to be Newton a theory of gravity. However, in the case in Mercury, which he ing the hearts planet to the san, less the strongest gravity one effects and has a rather elongated most go that it is typicallets the the long axis of the ellipse short deported bout he subject to the three digits.

the bousaint years. Still hough this effect is, I have been not a before 19.5 and served as one of the first control of the process of the process the element of the process of the proce

Light rays no must follow geodesics in space time. Again, the fact hat space is curved means that light or uniger appears it investigating times it space. So generates a viriliproducts that the bonn by gravitational bodies. For example, he theory predicts that the ight cones of points rear the sun would be sughtly ben inward, in it of the mission is not the sun would be sughtly ben inward, in it of the mission when the sun would be sughtly ben inward, in it is if the inperiod is passively the single through a small angle, taken in the single to appear in a conferent position to in observer as the earth. Fig. 2-9. Of course of the light from the start also we



As his territoria non a teach reaght as his rest of a teach reaght and the state of the state of

the the thirty wastered DON'THE REPORT OF SHARE A STATE OF THE THE hosey I was to a work to and got been to be win salahry and a de a system to all tedacting to be that he is the epoch es Will Hir tas progress of the state Metalexic to charter grants Watt . the Literate a surrigation of any hor In rind ( encrely each encress as a least A PARKET THE PROPERTY OF A PARKETS rong rely ray and the place as well the case of how become a comment of the test of in gar are It man the news or according to KANANG LI PENGET AND A TANANG A In second The complete the tensor of firmed by a number of later observations.

A life per a real property of a spirit of the second of th

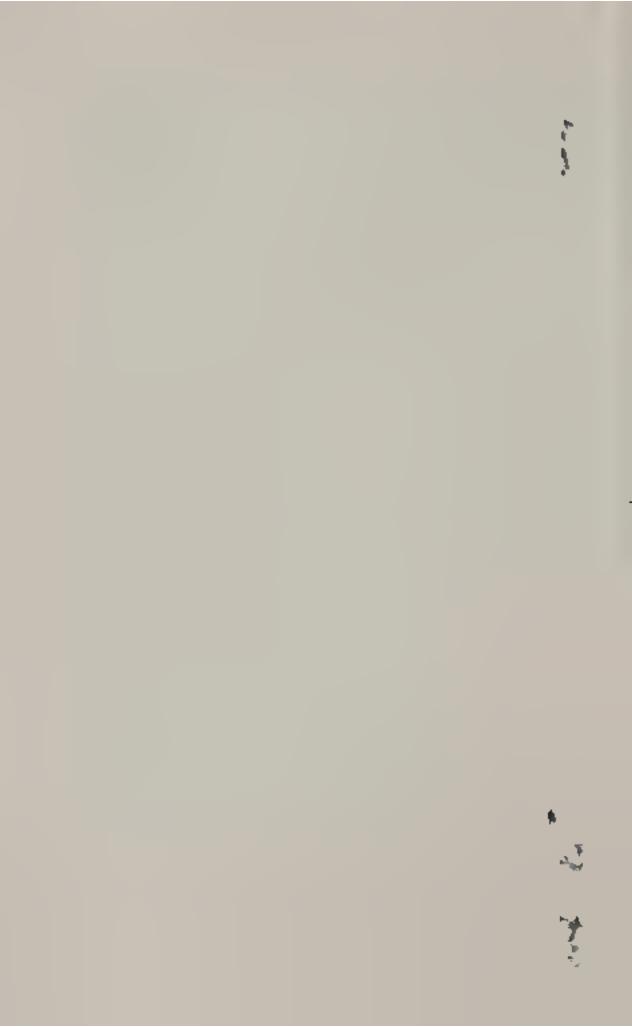
ener in he spece. Chicks at I force heights with he earth is now. I considerable pract all in whate with the after the relation and the many parties are the general to pre-contrast percentage at the second with the pre-contrast percentage at the second with the wrong by several miles.

Note that serve that satisfies a solution of the serve of the serve that satisfies a solution of the serve that satisfies a solution of the plant of was Separated as a The first two was larger taster than the serve. Thus, the interagano one was the contract than the street I tastes the determine in agree was late very solution takes a be much larger tane of that was a west or a part of an above the was about the solution of the serve that the solution of the was about the solution of the back of one of late the resolution the was about the total above the solution of the back of one of late the resolution of the solution of the back of one of late the resolution as he was about the solution of the back of one of late the resolution as he was a solution of that are less on where he same how he was any

the reads who early the write that the same tested he who the prince the first was true even at the special theory of related to the common meditions and report 1 for the case space and time went to to to the contract of t

The struct of lowever a crite interest to the general theory to relative a Space at 1 income now as any process where is only to new traditive acts, that extress on abord a size as the first to the space time a loss the way in which bushes anovement interest. Space any cinematorily after but a source afterest by every hing that however in the inverse of a sounce and interest about even a new at verse with a time at the strong dispersion into a verse with a time at the strong dispersion into a verse with a time at the strong dispersion into a verse with a time at the strong dispersion into a verse with a time at the strong dispersion into a verse with a time at the strong dispersion into the conserver.

In the clawing disaces his real naturation in altapace and one was to revolutionize our view of the increase. The clad deal of an essentially unchanging an erse that could have existed, and could continue to exist hore en was remaced by the notion of a dynamic, expending an erse that so meet claim e began a hore time ago, and had might ensure that so meet claim in be to are. That revolution or institution of a transfer and the next claim in the total entry of the services. So to be he scarting profit or a particular claim, which is the entry of the artists in principled that the converse mass like a long only and possible in entry.



## THE EXPANDING UNIVERSE

If we mike at the sky make at mountains again, it mightest hip is I me sees are like a cilbe the piacets Venes. Mirs. in terrain 15 stores I'ment also ke a ryllinge in her a series which are list kerfor William out much further manus Sein in setting sites dia spear is the go very sightly the rights insitely is sucrebill at is be earth of is around to sun have constructly accordang This is secouse they are comparatively mean trius. As the earth gives recent the Sun, we see them from on other positions ago not be packground to more listants ins. This sit many herause the abies as casure lines by the case are at cause stars from as a meaner they are the more he appear to move Inchestes sar well-rayin. (entersteme to be about a rlight years owns he last tem thousand about ther years to reach earth or thou me my time my man , or a less Most of the other stars that are ble a bonake tieve it with a a few hartest place exotix har six he companies as a incre eight gir minutes way the inter-stars opport spicae of were the aghr sky but are particularly empertrate in we bane which we call the M ky Why As inglagings 1750, so in a similarity were suggesting that the appearance of he M ky Why child be the above of a similarity ker or spiral the vine excepted what we new car a sport gainty. Only if the text is later the astropheter Sir W. rain Hersche or firmed this term by paint ik ngay of high githe positions and a sinces it was a riberty of strick high githe positions and a sinces it was a riberty of strick high githe positions and a sinces it was a riberty of strick high githe positions and a sinces it was a riberty of strick high githe positions and a sinces it was a riberty of strick high gither positions and a sinces it was a riberty of strick high gither positions are described by gardy this century.

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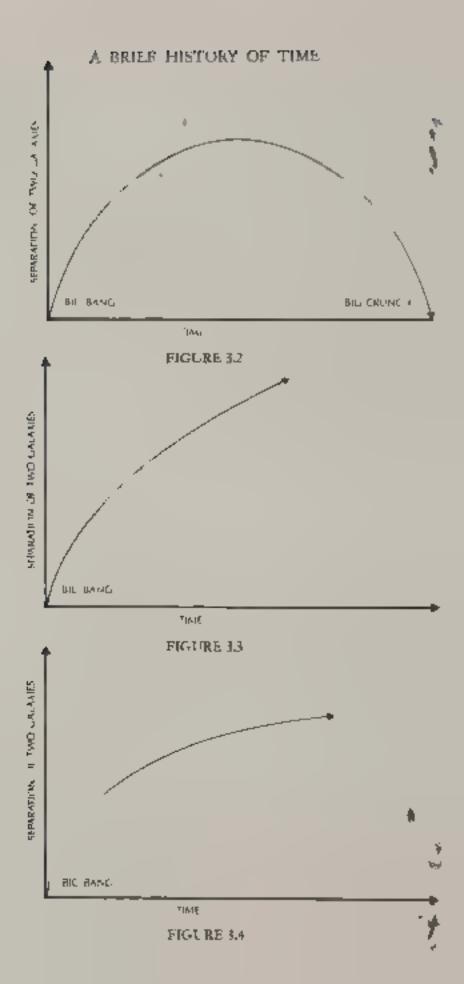
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## THE UNCERTAINTY PRINCIPLE

The success of scientific theories, particularly Newton's theory of gravity led the French scientist the Marques of Laplace of the gravity led the nineteenth century to argue that there should be a set of scientific laws that would allow as to predict everything the would happen in the an verse of only we know the complete state of the universe at one time if we know the tost ions and speeds of the sun into the planets at one time, then we could use Newton's taws to only use the state of the Solar System along other lime. Deferming some seems fairly obvious in this case but Laplace were further to assome that there were similar aws governing every ting else including human behavior.

The contrine of scientific determinism was strongly resisted by many heapte who test that it infringed God's freedom to a cryane in the world, but it remained the stand reclassion to a science unit the early years of this century. One will be the necessary that this he of with 4 have to be an and oned to me when courselves by the British

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ic is only the chicevat was of the wire I that may be described in thise terms. There is thus a duality horwest makes an iparticles in quantum. mechanics, for some purposes it is 10 pd. in hink of particles as waves and for other purposes it is her or to hank of wales as portues. An important consequence of this is that one can observe well used edinterference he ween two se sich waves an particles. This is to say the crests in the set of waves may councide with the troughs in the other sec-The two selse waves tiene accleach ther as reperthonally nguyto a significant is easiline in anticased. Fig. 4. After are sample of interference in the case of light sittle colors that a colores seen in soap bubbles. These are clased by reflection of light from the two siles it the thin him of water forming the bubble. While I got consists of light waves of a different wave engths, or colors. For cert in wavelengths the crests riche was as reflecion from the sile in the soap film come in with the troughs reflected from the other side. The colors correspond ng to these ways eigens are absent from the reflected tight at the therefore appears to be colored.

merforence can also occur for particles. Secal to the day by mendaced by quantum methods. A famous example is the so-called which texperiment for 4.3. Consider a partition with well tarrow paracel such in the circle side of the port to in the places a source of ght of a particle far experiment to that is of a narrowlar wave engine. Most different will be the partition but is mall amount will go brough be

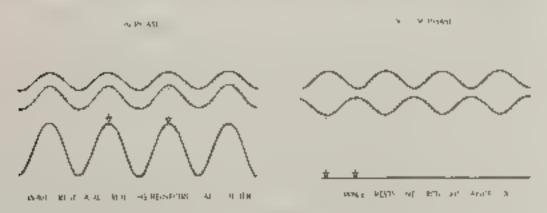


FIGURE 4.1

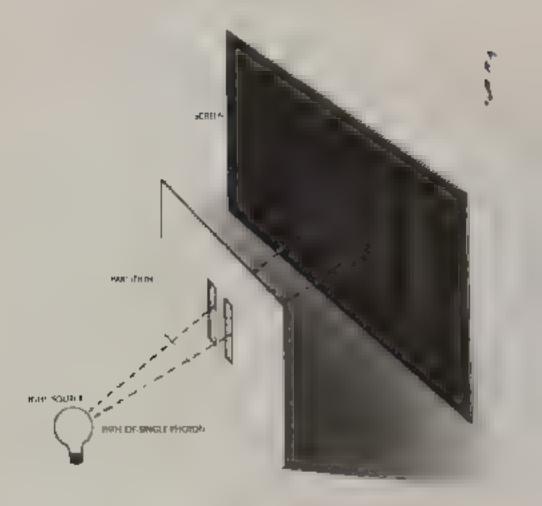


FIGURE 4.2

sits. Now suppose one places a screen on the far's deaf the partition training the Any normal the screen will receive waves from the two sits. However in general the distance the light has to travel from the source to the screen was the two sits will be littled to This will near this the waves from the sits will plut be in place with each other when they arrive at the screen on some places the waves will cancel each other out and in others they will resisforce each other. The result is a characteristic pattern of light and dark fringes.

The remarkable thing is that one gets exactly the same kind of fringes if one replaces the source of light by a siturce or particles sugh as electrons with a cefinite speed this me as that the corresponding waves have a refinite length. It seems the more peculiar because a rine

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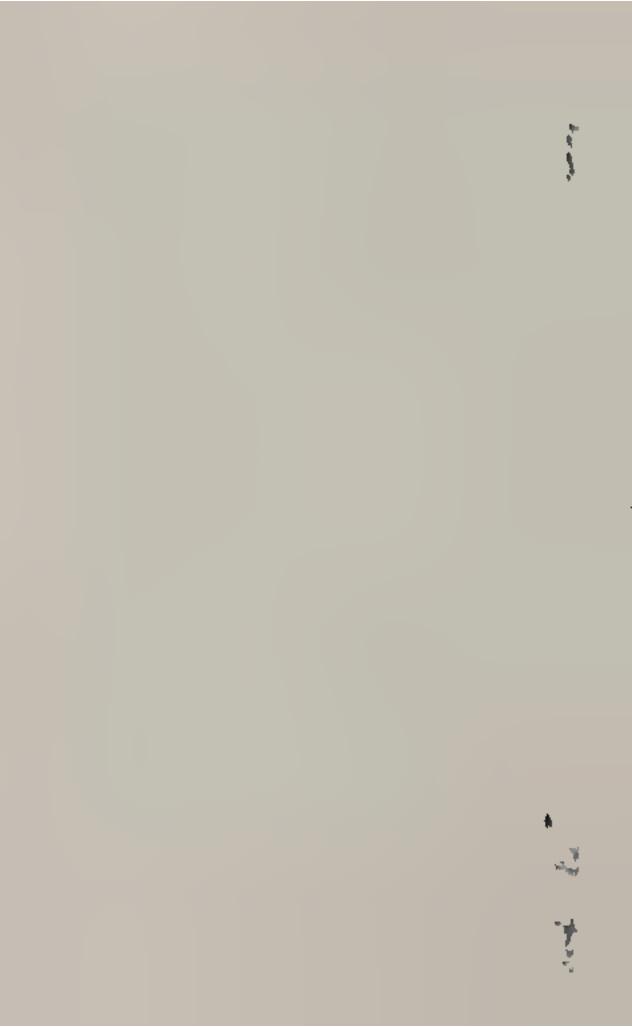
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## ELEMENTARY PARTICLES AND THE FORCES OF NATURE

ristorly be even to it if the matter in the up we se was made up of faur hosic etc rents - earth air, fire, and wher These exments were a e or by two forces gravity the rene ency of earth and water to sink, and exity, the towersey for air and the to se I his I was the contents of the universe into miller and forces a will used today.

Ar sie de benever inta marter wis communas, has si one chale to le a piere e mi etce neo smaller and smaller bi six i tour any limit me ne er came of against a grain it mat er that could not be one les wither A ew Greeks he wever such as Dem air tus, he dithal marker was inherently grant in the everything was made up of large numbers to crious I tereor kinds of thins (The world arum means and is not a Greek. For centuries the argument court need without any real expector cutter site but a 813 ce flerish chemist and physics: Joh. Dilton pointed out that the fact that chemical canpriorities I ways como ace lo certar proportions could be explained by he grown og together if atoms i firm un sicaled more des. Haw

exercises and the second state of the second second

But with a here with a time way on a little and answere it attend of salle Severla riper a said men I all a ge a star I have a rather to not pure deliters be the eretral that had a section that he thought the that if he has a server II use a contrat or the mostern A principle reiche mit die Aser leiten her se tiesebae in tarrecte cars are referrebe sele an lesseth toxic appropriate detse. We take he serer's History of white regeneral series was refer here electronic is state on by the sale he has be been expended in a to law les of the soften soft took I who are the the same of the data terretaries and the exercist a particle against as as as as a new man a second de ros et le el er sity analoging he was a what alpha is a war are waster a large, parkers aren of by taches seating at letter when they are a hitaging

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The first three figures is a substitute of the s

He parked protection of the production of the with the mar in since See a group where are tell a erice they are so have a poblicked rish haver to ar she became a hor greatly the over it at move, and a home of the or and term in co en many way We have a wave agree to with a server. I want to be A we saw the say and a man in charte so the I latered to be de art are the recorner to person he waster he was a good at he are to see was be to mal sacres this are at the or as his a confer ergive and possible so the expension la expiscale who are the analytic carry a various and a castir in in, sick in the nix is in the analysis of the first with the this was a bother after bett to the accepted being remain The energy tanks had a parado a contract to the parados to get a few comments of a finite contract to the terms of a finite contract to the terms of the by more energy star implication to was a server the least the property of the contract o burning pass with the constituence of a phyther Indisexpreparation to the state of the to drive to More to the se have able to the course of the he know that somethers in the antiting that as a rel os te ciro e is Am a we know the part is that were then the comen to be and a new tent in the Successful es My hack was at his configuration of the from the connection as I says or self-a sare respectively newes have sent treated as a strebelle of daws har a are very or acre and any a title to but it was that reas appropriate for the last see in the contractions high the supported that he had a combern them. ems of arts a lib supar as a average a day of mass as think the way are the garden for the party of the party of the an, by Hover have net read governor quagram Meant the spin of a particle particles to not have any well defined axis. What the spin of a particle reality to is used a dot of locks, we from different directions. A particle of spin to stake a dot of locks the same from every direction. Fig. 5.1 is whiche other into a particle of spin to is, we an arrow to wise effective from different directions (Fig. 5.1) (in yill cone of xill range occupie elsewhat an 30th degrees) does the particle lock the same. A particle of spin 2.5 is kein double headed arrow (Fig. 5.1) it tooks the same if one turns it room half a revolution. By degrees) Similarly, higher spin particles like the size of one turns them through the size of one turns them through smaller fractions of a complete revolution. All this seems for yes ranghiforward but the remark and fact is that there are pictures had do not ook the same if one turns them through just one revolution, you have to turn them through two contribute revolutions. Such particles are said to have so in

Ali the ki two particles in the an verse ein he divided in o two



FIGURE 51

are ips letters it spin which make up the matter in the universe in proceedings for a which is writed see go trise to be reserver I may enjurishes. The matter particles obey what side rel Laury section night he pie in his was discovered in Lins by an Aurician and We thank ? It for abich he received he Nobel 2's ze in Has He was be an hetypolitheoretical physicist of was suice than that is the try that it is the same town with I make experiments at areing Paul sieve as in other clease that the similar partial soar potents in he same star that is they cannot have both the same post or ar I ties me encis, within he mis given by he wier rapes or all I elementated principle siera a hera se elex alos who must or parties to be made a large to a state of very high lense v ment applicance of he forces produced by the particles of spin () a 12 th are eperates have sign as y the sale more my three must have I ferreit on a test which means that they we have stay in he same past a forling the world had been created with a fate co is a principle guirks to a and form separate we felt or to the same trans Nor a widthese taget or with electrons for separate weather as a Three was la calapse to term of roughly uniform, dense "soup"

I horacine of 1.8, who has the electron and species by Paul Draw on after wave extends to be accused Professorship. Mathematically at the 1.8 who has the accused Professorship. Mathematically at the 1.8 who has the accused Professorship in Mathematical than 1.8 who has 1.8 as the resolution of skips of the read of the accused to the paper. I do skips of 1.4 to 1.8 the same of the action to 1.8 page. I do skips of 1.4 to 1.4 the same of the action of the action to 1.8 page. It as the reconstitution but the following the resolution of the action of th

which that another the new tree are no particles, the are pointly as are the same as the part of the serves. There is the whole apply or brand an perior to entre art arteces H weser tions to capturely thing to ake to as You will be a capitalin a great Hish of the The passion of was there seem to be so mans or relativeles and quarties of the expect terrely to to trant on a I shall return to it later in the chapter

Big the true bick, the forces of litera icos heissee matter party es are all supposed to be carried is lart less to origers in to I or What appends that a later particle such savel etc nor i 4 rk consistence across par are the result on this en ss in takes he's hery take namer particle. I be to reclearly proporticle the college with a street matter partie round to absorbe a Trive of some name the second of the special particle places at there has been - 4 be see the as a matter articles I is an it a mant property at to force area of the less has to a lord region to the season, rinks this means hat there a no man to the nominer that an he exchanged and so hex and ersemant out to However the I we arrange to show aby was two be should practice and we about our werear the Istance to the torough to they carry a have one and one toget the laber hand, if the base correspond art le have a mass of he town to be cesses to ong range The the carrys is not discardianged to a in noter partices are said to R er al nort es recour in he real partners they cannot be rest sie test 1 by hartice letrear Weiking they are however be acres that he have a measure or earl they goe there to theces forth course characters hart as a spirit in a maney stronger of if shows is real parties, when they can be recelly execute, They the allegate us as what are said this is well early uses, sub-sistens of plantage and discuss They may sometimes be the war noter hart a commercial with root or the exchanging creatified arring arrely his exhibit reflective received torcebers have er rouses to other whome to see a subs which can ever be see the atented. Independent moves, as an about a constraint of the passes of the base elect of a where I stock category attracts and be a cape a stateour atea messa. In the passes we will the passes of the p

The his category is the grassic total trace. This is a spinioreal s every particle felles to a creek grant y accessing to smasser the ex Gravity's be wrakest 4 the four forces by a ong way it was weak that we will not notice that were than teres proproperties that the national exercises that the and the agents at active This means that the sens weak gray fat a wife is between the today has partners in two large will est such as the part in the in can a aclu, to prince a significant force. The other three theres are either shoet hange of the supportants a machine a souther ments where we have on fire and one for the person has the was of look put the grave are all the helpice between we have or was is particle as sengial in the particle distribute of grant in Thichas ne laste it was so he tire that tearn was disto go The grast a soul once between the sup and the eights as erabel here hange deras this between the part estre trake in Pese two waters. A me ight the exchanged purposes are in the thes. certains to testime a measure eletter they make he earth ig t trans Kala asponsinake g wat classed, the site walke b grassia dia wales, which are very welk and so this to least that her have not yet been absence to

Then & a prestee criting . fire was the areach he that scharges per ices keep to a separate a tenth to be with ancharg I part jos such is graiting It of and situager han it greated that are he electrical richards as a letter was about religion of the properties as the west to the years after the act being the heart to a fer How sittle tears worked a fire organist carl git The fore reservoir spriss are congress seconds as in the fire more than game a right hit the first is default a little of possible at the right sectoring. A large bis you be to be a fire-She contains meaning I to been positive and according Thus the atric or a Trajan el residence a for a clears regarded to the rout and here seems to pitch to say est a line se on he small scales a or s - es an araphaga to a schooled The electron good as a by to neglish characters on assistable, rotas remail are search, sector at combit the control of the season of greated had a trictly a seat to entitle and the Total tree a traitities on synctotes as many acres within which a harp princer exercise soless particle spirit emissions to that must have a spectare and appropriate laws when a electronic potent. In retarriber crement alrike tas steen and a time pattern service is the application illocree la costice at avithe il territor historia. the man a state of the state of to place od switch an atom times we proceed a a to mean ten cus ener per en y las ses phene the photon, so it is absorbed.

The same of the sa

Harvard both proposed, hear is har an first his interaction with the ele trom gnetic force a state Maxiel handel excress. I Magnetists about a him recognist earlier. They suggest a that in ad at of other photon, there were three others in the relies known or extrem as massive vector bost is a correct to which tree These were case, W+ rendered W you W gratery W in hase and / opropiy need / no ght and each has a mas around H G V Cont status in grandestrions of a house ! million rection vits. The Wellier Salam recty on buts or erty known as spontane as syn horry breiking I is means to what a pear to be a supper to completely filt that art is the energies are a tall to be 1 the same type of palice 1. ... interest states. As high charges a these parties behalf and only The effect is rether we he he as or to she effects, they see while A right engines when he wheel with in a skill be had behaves nesse talvery me was a respect to the Beller's the wheels away the energy of the bull leave axes, and a consert the bal In is not me of the tary seven sous in he seed a stary words, allow elergies there are the type of them so a silver the ball can exist the some reason we call by observable. is an elergies we would take think their there were hirty selen different types of bal !

In he Womberg So in this to doing street place and the photon would be true to a similar manner. But at the ower particle energy with the earth of the street and normal at that this synthesis you merry between the last text of the arther seeken W + W and Z which is entre large trasses make at earth of the arther seeken where a very short range. The last is a small to Weinberg proposed to the rest few mapse below to mand to be accepted as were not proved to make the reach the energy of the Cell reported to provide the earth of the energy of the extension of the earth of t

Weinberg were awar les, the Nobes Prive for a ses, toge her with Sie le. Grashew, also at Harrard with a sugge a dismillion a there is of the electron of the all weak no ear order in a mel committee was sparce the em arrayan not if having made in stoke is the discovery in 188 at CERN There is not epitter in North Research) or he three massive partners (1) have with a reco predicted masses and other properties to riskulla with a c several hundred physicials that there he a court feet the Nobel Prize in 1994 away with Singe vin it Mer to ath engineer who developed the artimater storage as elected at 1 % very of their its make a nark in experime 1, it is it is its you are already at the topl,

The fourth calegory is the stream notice force, which he quarks regether in the promonant neutrino at I hold site. It is not neutrons together in the naceus countries to a white this force is carried by a other spin I particle to 1 he have a whi inversets only with user and with he quirks a hear a pack are not has a curious property cale confinement and a so him significaregether procombinate us hat have not seed they not a little quark on its own because I would have the fire pre-Instead a red quark has to be to need agreen in a block with string of glooms red + green + his abit his to at constitutes a proton of a neutrin. An other post, in a 18 hours also inget a quark and an ant quark red + - then er are + - gr or blue + antiblue = white Nach or then then have the higher known as mesons, which are unstable occause help ark at langurk can annihi me each other prod a greaters . The profice Simparly combineme tyresen's he having is a good in tecan hecause glamms also have ellor lasteau inches a him rich inches gions whose colors add up to which Silb a color of time it unstable particle called a glueban.

The fact that continement, revents a first service, and act quark or glader to gracete to make the ance which is parks of

place of ar cles so no has me apher a Hacer the to a pher products to an an an or or a last men tree or ton. mike the complete parks as a manager to medial erical to ser place force seed that the the sine I was a hoper. How or experience with trge are le seele a resident of the and the erest of the months I what with the I be granks a light on the breed not be true probe to a constitute transaction between between and programs and other The solutions of the on the arms of the e representation to the termination of attempts the other than the said he compared over the and is a gran iter terry red T T str is not comen and r Be a the resistant across reach fit a grand or are they be enter a her length a egiste to ret rest at your a mile in the thick optain a new here is not in the acts a ratherpression of heat were heat or prophession in making expense to enter his man is set to regarde in the rell has a settle I see a least a vigor per me . H h strengt to erect gets a h r a han e hety that a to hard be duty and we had been while to a s AT CAT ETSINGLE I THE TEES ALSONIC CENTER e rgs he help nousehous sent at these tre to say the to a chare tree to be to be an about the transfer of any three The El Trais pre 1 . . this energy to steen than The adventish of the se become a self the a be used by his and thus his new disers the pin

the dealers have be estimated the set of the



FIGURE 5.2 A proton and an antiproton collide at high energy producing a couple of almost free quarks.

Arana units, the rick a rectiving to bork my However has as it the case of the decire magnetic in weak united the ry third are now energy a isoqueness of the heart that connectested

The risk of resting of these is the one circle hat process, which make that a fine process such as anticiprons. The reason this is possible as that a fine group in account onergy here is no essential. It ended between equark a flantar electron. The here of this inside a protect remon, by it not him to the high entropy been ingle about the circle to the very lock with form of hem may off the such height entropy of the group of the about the protect of the group which he is a fine of the death of the protect of the group which is a fine protect of the group which is a fine protect of the group of the group of the rest and the protect of the group of the rest and the protect of the group of the group of the rest and the protect of the group of the rest and the protect of the group of the same of the protect of the group of the same of the protect of the group of the same of the protect of the group of the same of the protect of

e emight hink this appeal and its a concerns out increase one supports of our production of the observing target amount of interest and place and particles of a service and better the one of the other productions of the observe and better the other of the observe and the other one of the other other of the other of the other of the other of the other of

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Even though it is very a thouse to a series spinitaneous proton decay times be that a more expense ence is a consequence of the reverse process the product of the reverse process the product of the reverse process the product of the reverse process in a product of the reverse process in a matter of some control way. There are no acceptant in a transition of the research of a matter of the research of the resear

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We have be real to that is to either a more in at an galaxies is made up of promission linear ons, mail recens a light. no trins, but at mission upon the orbit of the real fact by a most real at single galaxy be any that you we was logger closes and a the wondern and lates Wither Cope he can hat all goods a ore or posed a quarks to her that are parks, see a splant but some gasax is shown be man it a liston out the dier

Why she do there were man a requires a comparison with pretheremated maphers ate in ascent terangent in the surchers are ages salitie arise of the born some my hi te perks an in marks wal have a bar each other te early fixery a train verse his with a fiated an after a vimer Then who I then have been right a stars at hear n which himmy could have be per I by an it it be ties that previous an exact new way the line shall now con an increasing transfer in charles over their a torbice. numbers feach Assects exert the Isa my raste have be appropriate and high concer They also less be to the property antiquarks for its in a hiteans and iteas and attribute as arm of the organism of the I restaunt to the ers arts the eacher theaver hat the total exception with ghieronic refrese transcent roust tak the bowle should harlead to more proceeding attenueths. There is sometiment physicare not a cities of court ies. The process

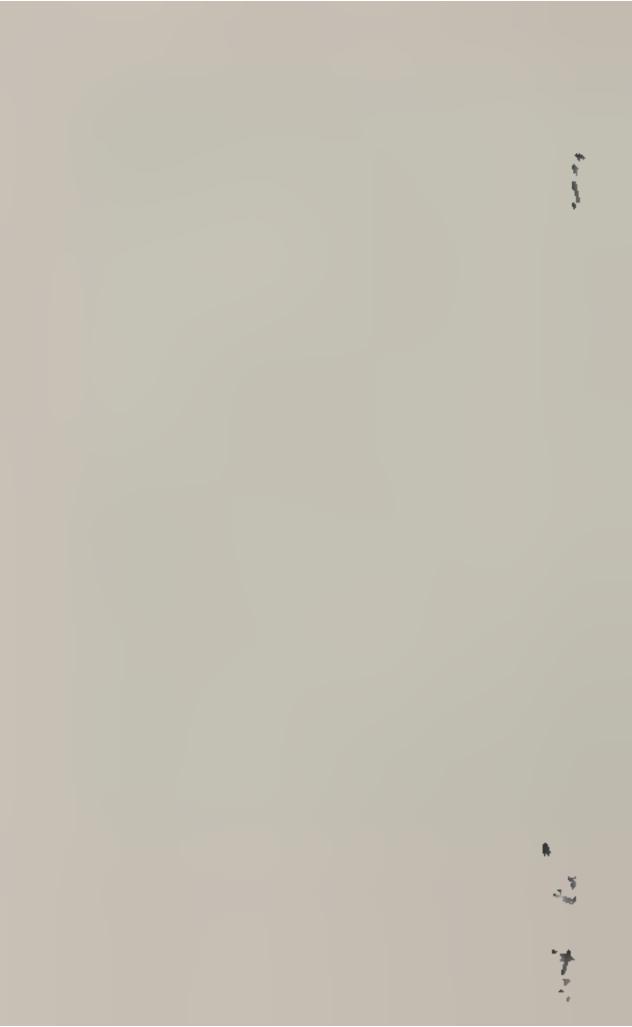
I pto the two is no by he can it has a mar a h . three separar sym tries a (P. 11 the sym try ( p. 14 that the assert the same of parachant master area. The same try Poregrand of the days are to room as only state and the rest make the mater make it a site of a a gor a gla and Ir then so as in right a market for the The state of means that we riverse traver in a moral a part well

a there is near she will be bright the sate for the nother a rate we retain the erver and he kwar directors of 1 \$ the is Abic and is not an in the and Chen Any Transaction of the second received the when his marries Por war a weak to new a wak the I end even to the two states and the Take at the experse and I comply the management of Carn Shieng W prived early on cores Sir lath is nouspet before and a support between to store its entrain historia freezione infrance in the e sons were a more in one or in that a little The I a margaretter in tax rece e to Nobille o er era I washe rild case at rather to a men of this a two female and the expects of art st behave a flerency term we amprice Neverth a compact of a conlape to coeste mare an installation for cost a ech tesa convarantes per est of particular was product from the little of the entire Americans W Croppa IV I have creath a nectsymmetry was not shower as the most of art in him exceeds Kircsons Can ha little ever water conclude Non Proce of the rivers of the transfer of the property of he universe is not as a upite as we maybe have here he

There is a notemator to serve that says has any to the person but a serve when he can be a serve when he can be according to the mere and a serve when he are a serve when he are a serve to the same in the case of the person of the Both to the first that the more than the transfer the person of the person of the transfer the more than the transfer the server to the server the server to the server to the server the server the server to the server to the server the symmetry T

weether a factor to be not been at the and the first second referred to the court of the series of the series with the act a long that the rear air a max A MADE TO THE SERVICE A STATE OF LEGAT TORSE THE QUEST STREET ST. TABLES I A DEATH COURT DO THE CONTRACTOR a deal to some the some the some of the some of the sound that the sound the sound that the sound the sound the sound the sound the sound the sound the soun That a sirly a law a war of the a d k t protection of the new are lettle a receive ce I hereger has an a ready house to be right a face of t a flex at s the a c of c here here some alm residence with permit MC SAFE OF ALL STANS FINANCIA STANSON OF A SAME The property and a series of the contraction of the guarks, and quarks antiquarks.)

to the light of the state of the protect of the and the state of the s



## BLACK HOLES

The terr black have such very recent original was conted in 1909 by the American scient still and Wheeler as a graphic description of the footback at east two hundred years to a time when there were two theories about 19th one which Newton favored, was was composed of particles the other was that it was made of waves. We was know that really both theories are correct as the wave are clear to figure turn mechanics, which he regards its both a wave and a article in other the heory but ghost made wie waves, it was not clear how the object them to be affected by gray by in the same way that curnow halls maked and planets are. At first people thought that particles is ghit traveled in a fely of so gray by worth not have seen due to she with the relevant to the associated by Rhemer that ghit traveled in a fely of so gray by Rhemer that ghit traveled in a fely of so gray by Rhemer that ghit traveled in a fely of so gray by Rhemer that ghit traveled in the property by Rhemer that ghit traveled the speed meant to the gray by might have an important effect.

n Blint & Philosophical Transactions of the Koya Society of London in

while he was a titha a war that was a factly associated cha anthream agree and he it a ighter i it escape is is he them to those the states of he starts of the the kits the sansground a rich in het real on agent very by Michiel suggested that there mugh the charge no now restors we this I we was I not be for to see the part and he last from them was latter burne confirmed be rappasted as a at Net of consequent we man such he has be sent a at other chak margine As sarrage sto war or . to a serial later by the French sciencist the Mary is a Laplace a pare to an product a Market Interesting a china Laplace in elected the explicit of an executive and an explicit the sistem of hellows on it that discretion is not a see to lost har twisa rizy le expe the part of there it ight no rinte faces ring to the terrept seeme have some hogy I would be with which my according to the wave hours it was not clear the would be alless by gardy at a

Newton's later 1 gray to receive the spece of light is well in a common to provide the care of light is well in a common to provide the care of the ca

I deleas at a wall-confidence the cornel within our at the rise on the case of a start started when a dige at a talk a model, he against arts to object on the libertous granted half are not As a contracts, he atoms at the gister to be atoms at the gister to the atoms at the gister and lightenter should be something as the gas to be something as the gas to be something to be to be the great at the great and the great at the great a



to al tosce territegem the has exist to be read in which he are the typichion or is on a substitution to strish e Hevan tone heat he screen to assert the has end like to an arthugense in craction as high super or race please there is a there supplies be agen. t Hampton the a sewall strain machinen At he was a the rule who to the great whether the more transfer near heavists a get with he the his nectiar reactions becausing he granted in minda beauthouser busewhen the mir genard at rink ar his Parita als the oreticasternament will to see that is not I in in because let strong any office in the The tree is to be the annealist at the arrace of American there is the same at some take there is a sub- again e might feel to can other the the same or I in years in a few and rassessors and escape in the masses as containing a masses a raim highest and riage of the day day. When a kind of the large fold states in frame some contract What regardingse of a safest ar smalle beet on the long

I shart as grade example between a characteristic of service to the feature of th

of gravity and the repulsion of at an session of the extrator of the last ust as earlier in its life gravity was bounded the the heat

Chardrasekhar realized however that there is a ment their put sion that he exclusion principle can provide. This the matter partities in the star to the specific hight. This means that when he scar got is their thy lense the repulsion cause. In the exclusion principle would be less than the a raction of principle Contributes that could sared more than about the and a laborative that a could sared more than about the and a laborative six of the six is they know as the Chan le sikhor must be soon principle mass is how known as the Chan le sikhor must be soon far discovery was made about the sar entire by the Rossian scenario are David is chandau.

This has serice sample at any for the different assistants less to as the Chan frasck har and interesting and serile as which possible holds are as a which hard with a radius of a few the using ones and a central holds are is in pranciple repuls on between the electrons in its matter. We absence a large number of these who less and Series to nect he first to be discussed that start that is orbital series as the brightest are not being around Series, the brightest sign of the night sky.

Lane an pointed of the here was an her loss, either some for a sar also with a limiting mass of bout one or two it must be missed the supported by the exclusion point pacterpt some between the rate of a military were therefore a said promose rather than between electrons. They were therefore a said neutron stars. They were a have a rate as to be ten missed of the rate of the content of bunk edge in home of tens per labe.

A the rate of the were that predicted there was no way that no line of any cools he observed. They were not act they reflected on a much later.

Stars with misses above the Chan Ir sekhar limit in the other hand have a higher him when they come a heart detical read In some cases they may explose or manage to a now of each size manage to a now of each size manage to a now of each size.



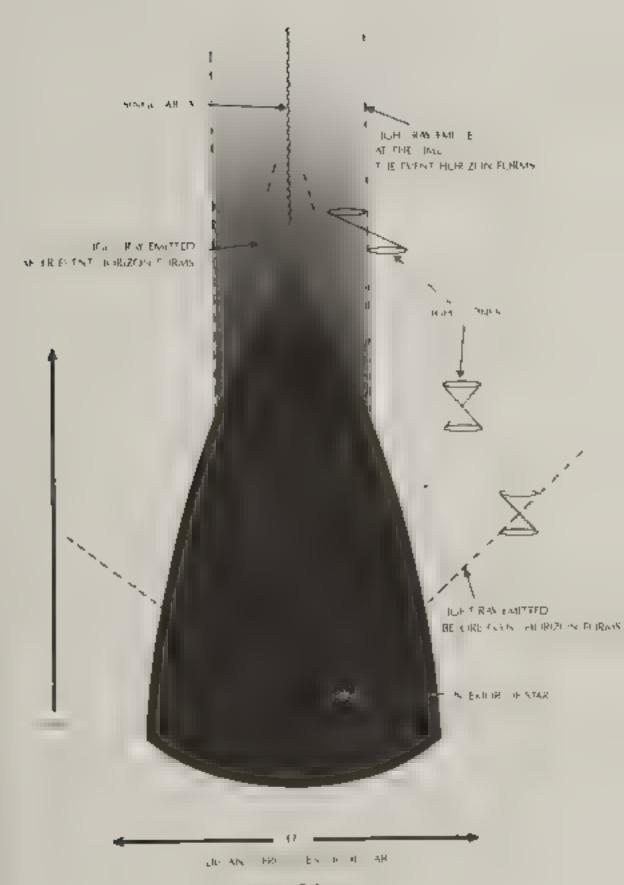
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The care of a mest explorer to a most hard real and he a like a little of a care of a real real real real backs and he are the little of a little of a



FIGURE 6.2 The brighter of the two stars near the center of the phinograph is Cygnus X 1, which is hought to consist of a black bale and a normal star, orbiting around each other.

evicence in favor of black holes that I have concelled the bet I paid the specified penalty, which was a line year subscript on the Penthouse to the outrage of Kip's liberated wife.

We also now have extreme for several other place holes in systems. Like Cygnos X. In our galaxy and in two neighboring galaxies called the Mage and Chieds. The lumber of black holes, however, staining tertainly very in the higher in the long history of the universe many stars must have purpose all their nuclear ties and have half to collapse. The number of black holes min well be greater even than the number of visible stars, which totals about a huncited holes at the rates of one in our galaxy a one. The extra gravitational attracts in its actual arge number of black holes can be explain why our galaxy rotates at the rates of ones the mass of the visible stars is not a light to account for this. We also have some evidence that there is a manual arger black independence with a place of about a hundred thousand times that if the san, at the center of our galaxy. Stars in the galaxy that come row near this black hole sydiae.

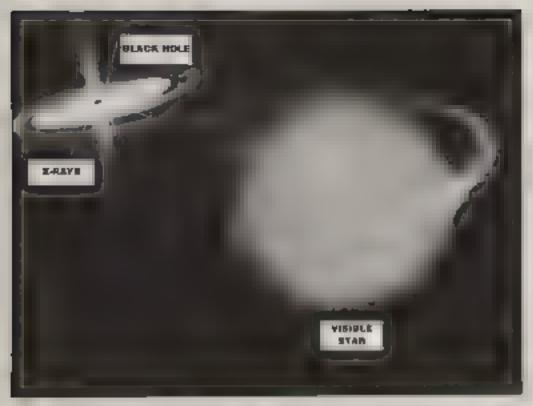


FIGURE 6.3

the same by the forecast in the gray arithmater as the destination of the destination of the same has the gas that is thrown a forecast rs. with a ward the back hole. As in the case of even is \$2.1 the gas will spiral award and will record up, though not as much as in that case. It will not get but enough the total \$2.25% by the wall as with for the very compact security of riche waves in the place of riche waves in th

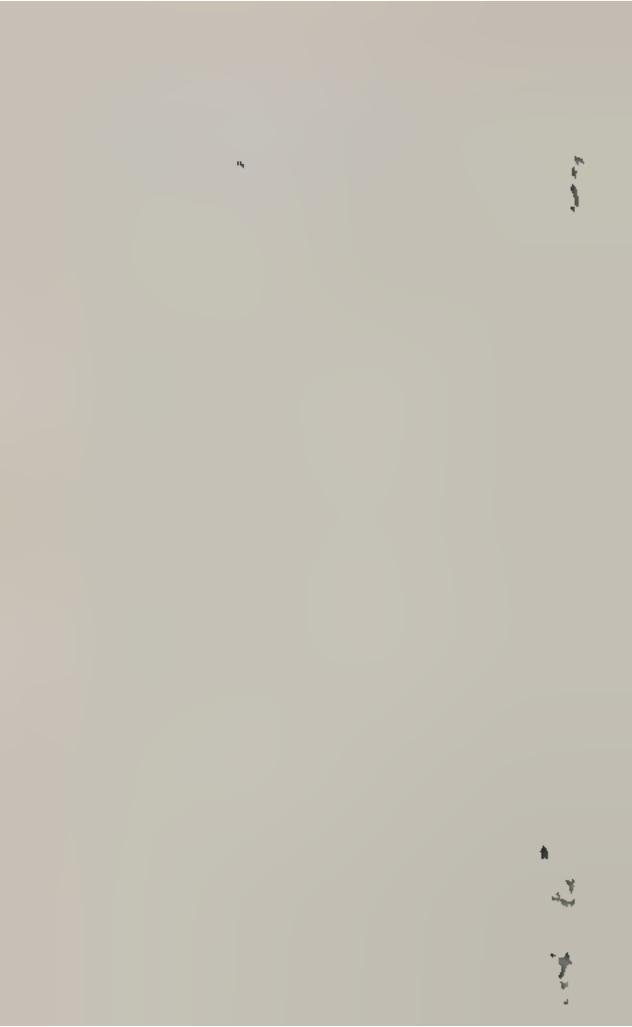
s brought the said architectural larger back hors, with masses of about a consecution of the sample, observations with the Hubble telescope of the greaty kings as MR reveal that there is a cisk of good for give are across onto ng doubt a corractive to assate million times he mass of the second back hole with a row less consistent and the surface of the same million times he mass of the second back hole with a row less constitution of the surface of the

less on arrest & to energy of history who have blake ender the she treated case ng in I a green to first & adverse bern high ending with the the part of the week to the that or T in was the a st protein a family like paralisation to atasefa ingalaxis in the k hale has a remark pertailer appear Such as re the things and the talk and the state eniso the published to their here attached to be to see exhibes he that if yo Show keeps a form on the way ger remainders became been says and when the SER THE ISS BUTSELS OF SUCH SUSPENDED SILES TO BE the erec prosess senat he have been sent for better In an k along on month of the se e en as east she seen the street we shall be each were navers by the word of process on Worder the colse by the abilities of the state of t traction to the state of the st materially certification in the state of the ce is they went be no to done to be to the a possibly chase the content of the track of some or FIRE E PERFORME A Symmetry transfer out of the person of the beautiful and the section of the se take was free bir to me ter it early excess to a stagen perieca so a to a to a to a constant a se distribupate operation to construct the text of the text a Be we know the star star we's carreg out a because I rake her ner neth lesser was likely the pier a in it orm y ser butter the resemble in a series being a temperal together in stars and galaxies

When the lease to the state of the state of



there werse. The har has black he es with masses more than a bin said of the formational inflaence on other visible matter or in the expansion of the universe. However, as we shall else to the cext chapter hack hises are neuronally back, term they give the above body and the smaller they are they are the more they also. So paradoxingly smaller black, roles might accordingly are not to be easier to detect than large ones!



## BLACK HOLES AIN'T SO BLACK

Before 1.71, my research on general relativity has concentrated namely of the question of whether or not here had been albig being sing farity. However, one evening in November that year, short year one in high or high of my analysis bed. My disable to makes this rather a slow process, so I had proxy of time. A that date there was no precise definition of which high its in space time lay inside a black hise and which avoid soft. I had a ready discussed with Right Penrose the idea which in a safe. I had a ready discussed with Right Penrose the idea which in a safe I had a ready discussed with Right Penrose the idea which in grant to a sarge distance which is now the generally accorded cebin than It means that the boundity of the black holes, the event harpen is formed by the light task in the ustiful to escape from the back hole hover, a forever, ast on the edge. Fig. 7.1) It is a bit like run inglaway from the police and hast managing to keep one step ahild by not being able to get clear away.

Yo kienly I realized that the paths of these light rays could never approach one another. If they did they must evertually run into one

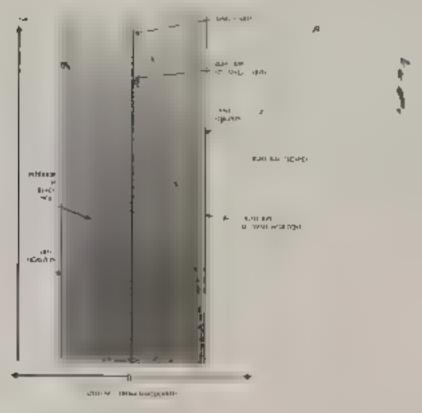


FIGURE 7 E

another It would be ike meeting someone else run inglaway from the process the apposite if rection is no would both be laugh. Or in this case fall into a black home. But if hese light rays were swithowed up by the black hole then they could not have been on the boundary of the black hole. So the paths of light rays in the event hor in hard a ways to be mining parallel to, or away from each other. Another way of seeing this is that the event hor ain, the boundary of the black hole, is the the edge of a shallow. The shadow of impending from: It you look at he shadow case by a source at a great is stance such as the vince you will see that the rays of light in the edge are not approaching each other.

I the rays of 1ght that form the event hor zon, the boundary of the black hole can never approach each other, the area of the event hor zon night stay the same or increase with time but i could after ecrease because that would mean that at east some of the rays of the could be at the c



in the boundary would have to be approaching each other In fact the area would increase whenever matter or radiation for into the holes have (Fig. 72) in a two black holes to like any it merges a igether to form a single black have the area of the event forms on the final black have worked be greater has proper alto be autoof he areas of the even horizons. The even her zons area placed an important restrict months also also behalf or of black holes. It wis so excited with a viliace cryithar local notice much sleep that hight. The pass hay I ranglup Right. Pennise Fle agreed with me I have notated been using a wight a different definition of a black hole. He had been using a wight a different definition of a black hole. He had not real action to the

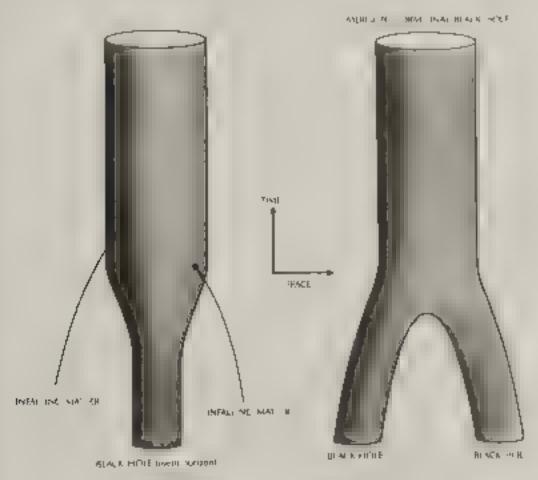


FIGURE 7.2 AND FIGURE 7.3

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The nonecereas apprendice to a back holes. As considering the experience that case or a confidering to the present at the present that case or a confidering to the present that case or a confidering to the present that case or a confidering to the present that case of the present that case or a confidering to the present that can be the confidered to the support to the confidering the confidering to the confidering the co

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The second and of thermodynamics as a rest to the ways than that of a relians the epic was as Scattering or a conexample because it lies but his fastack of inflict all of the cases. The prompts ty of all the gas remove the plant was made found in the half of the historia were into a line and the same to me had can happen However it has as a there seems to be a rather easier way if so it is to see the seems to be a the wisome major with a statement growth a six of a with wack he e The total entropy of a termity le hall and had www.t.peca decourse still hat hat te in the will ha the entropy has leather black hole has not post on the same of a neway to lock inside the hall a see an are had to en may the matter inside that It will be the land the man some testure of the back toole by which observes and a fact of k second to thentropy and which was a concept and at a carrying entre y tel into the b h ball 1 1 w , t car eases here also see that the area of the electric receives the case for the electric section in the area of the electric sections. matter te into a black hele, a research victorial in the first a the Bekens ein suggested that the area in every very a wind measure of the entropy of the black hor As many of the great and te population the area diseased the contract of the second the sale of the entropy of major on the book soft a be to at horizons would never go down.

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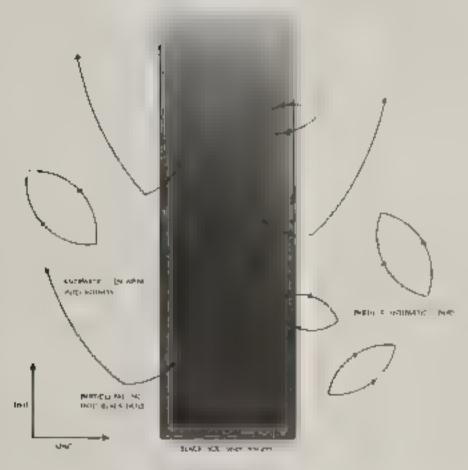
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PIGURE 7.4

emperature Solas the black hole loses mass, its emperature and rate of emission increase so it loses mass more dulikly. What has beneather the mass of the black hole even early becomes extremely small is not quitely earlied the most rescale to guess is that a would disappent completely to a tremend us hold burst of emission equivalent to the explosion of mallions of H-bombs.

A black hole with a mass a few times that of the son would have a temperature of only one tenim, a nith of a degree above above to zer. It is a much less than the temperature of the nitarowave racial list that fills the universe laborated? The above about zero is such hack holes we also emitted the less than they absorb. If the universe is restined to group expanding occurrance the emperature in the microwave radiation will eventually decrease to less than that it such a black like which will,

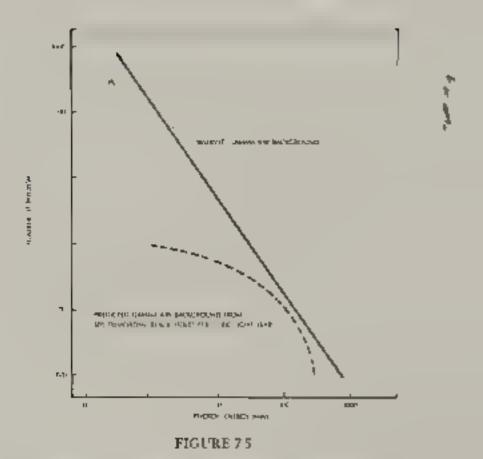
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next black holes a recently mover to not be any color to the war library in a state of the active how he has been a more of a present to extend the move in the move of the hore to any how he had not a state of the hore to a state of the hore to a partial to the hore of the hore to a partial to the hore of the hore of



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quantum principle tells as that each gainma ray quantum has a very high energy, because gamma rays have a very high frequency, so it would not take many quanta to radiate even ten thousand megawarts. And to cliserve these lew luming from the distance of Pluto would require a larger gamma ray derector than any that have been constructed so an Moreover the detector would have to be in space, because gamma rays cannot penetrate the atmosphere

Of course, fight ack in easy case as Pluto were to reach the end of its act and blow up, it would be easy to detect the final burst of emission Birth the black hole has been emitting for the last ten or twenty browson, million years, the chance of it reaching the end of its life with in the next few years rather than several million years in the past or future is really rather small So in order to have a reasonable chance of seeing an explosion before your research grant ran out, you would have to find a way to detect any explosions within a distance of about



a glace not here a partition to the har her a list to a tes of given a medit to make term around of the In the recty to some the many operations and and tike to play in this is the contraction the sky like I have don't combine outs to be a postermore or here we were copy he are nersera the transfer to white earlier the inflorm before the area has he surces at the report of mangage or right case and and a late on the are about a again they was the comchild a to rice and begins a flercam to energy softer account the astense enclarate tegets had not profit with the known to some were seeings to first to the temporary of week appearing to a fact the is as were to be have a treat so sell of the recognize the her red to possible of his his ordinant ray bursts, such a I to the man see he a short a distribution to the fact to ers war and wall was a respect to the letter as the relation to general restricts

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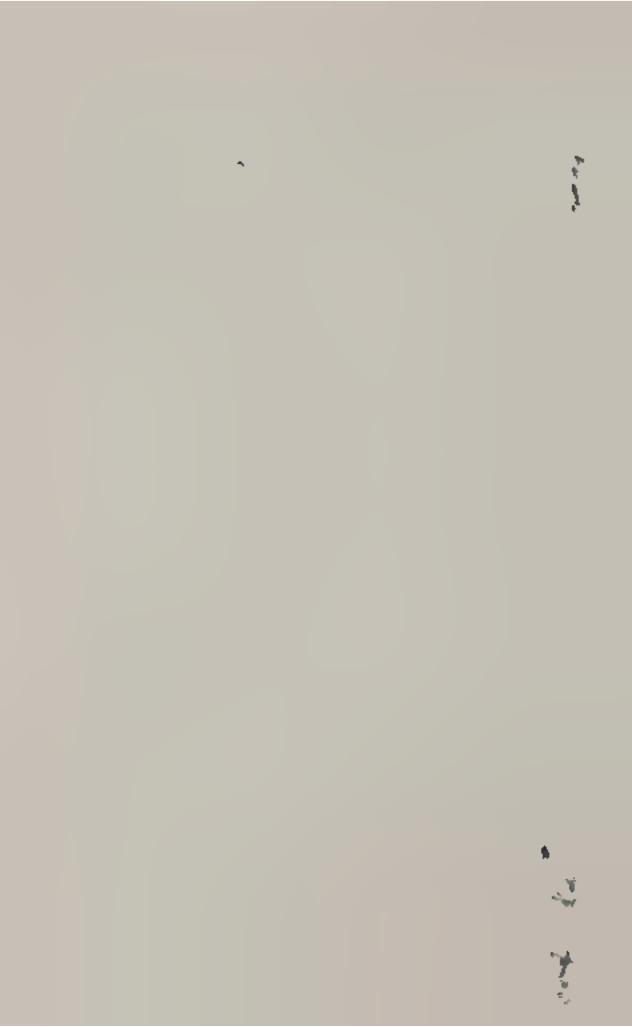
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The existence of radiation from black hopes seems in the half at all of a desired as home as health of treatments bleak as we meaning the contract talls into a black how its mass with the remarked to the consected of the form of the allow This, it is sense the astronautial horizontal forms of the appear sort of minority, however because and personal independent in the first astronautics of the acceptance of the the astronautics of the lack hole two their personal independent as he was term apart inside the lack hole two their personal periods that were even calls on a tool by he brack hole would in general he defend to the introduce the mode up the astronautic he appears to he appears to the acceptance of he astronautics that mode up the astronautic he appears on the appearance of he astronautics at well as some are would be his mass or energy.

The prexitational used a lerive helemission from high holes are work we say to be such hole has a mass gleder to make from a agrain However they was reak own or he contact the rock was a which a smass gets serves all Termis is a continue serms, on that to his kind with the astronomeration, a single region of he on serve to kind with the astronomeration, a single risk of mathematical and a serve the help to the following mathematical and a substitution of the first serve receives hygopera relativity. However, to me hope the mathematical and a strong mathematical about a massiver plant in such a whether soft a arrives which a whether soft a arrives which a whether soft a arrives which occurs in quantity gravity. For mathematical at the core strikes is described as a membrace to appreciate the mathematical at the core strikes is described as a membrace to appreciate.



to past in gravity based on Richard Feynman's deaple a sum over histories. The inswers that this approachs gges sifer the origin an five of the universe and its contents, such as astronality will be examined in the next two chapters. We shall see that although the talescent type properties in that one in the accuracy of a lour predictions it may at the same those to nove the long amounts unpredictable by the occurs at a space-time singularity.



## THE ORIGIN AND FATE OF THE UNIVERSE

nates in a general theory of relativity in a soliver of the clear that aspect time began at the big large single arry and would to me to an end either a the mg crane's singularity of the whole universe rece apsect, it it a singularity basis a back hole of cloud region such as a size were to collapse). Any rouner that tell into the hote would be les royed at the sing lands and only the gravita ional effect e to mass with I continue one fert outside. On the other and where op a un effects were ake a traccount it see nec it is he mass at energy of the matter would eventually be returned to the rest of the aniverse and that the black be e. along do this is angularity as to t water evapor to away and finally I suspear Could granted a chanics have a logically dramatic effect in the big bank and big crune i singularities? What ready happens for ngithe very early of iald stages of the universe, when gravitational he is are so strong that quantum effects cannot be ignored. Does the universe in facilitain a beginning or an end? And if so, what are they like?

Three gheat the 1990s I had been mainly studying thick he es, but

1 18 315 tranquestos au trapalacithe on erse was reproducted to her att better the or the seeings organized by he less is no Value The such are Charlesth . magaze sheat racwe trease anthologous cost documentation of the for San a to some that keeps not a police special set an eight wings. At the end, the elegant to be to the and were grant lan mentate Pope He entre was tracte startled in 4th to ereater the goal's attending not require out to be be by the set because that we trice to make of Ore who is therefore the work of these I was go then hat he I and he wither a control of the following the principles to the same to the section in the same mens the third no box of the territor of the severe to shore the fate of the enach at an I to I a wrong a most went a portly feet or "the spring of this night in her night as 300 years after his death!

In order to explain the less but I and the propletial or about biwill in minechan es may all eat the countries and a single is exerse. I see essably her our were ach the prierry acieps the cere die whitees as a rusing to when who we are the but he had must . This assimes that he an acree constituted is a first main in tide. table back to the name of a horner actions has some a arrive expands all it of crieria and in gots, were ill in this ense embles noze to temperature this sit is necessity and the many a meas rest the at the foreign makes of the fart less traceof and he in serse will a thore a contract the material that there is much resupertion steam to the remediate the series the fift your fiscale and the literative and fraction er or to put ar or electromagnet torces. I ray her care I if we work expect mer es the mire teach personal mp my har M mover ever the view diprice a horizon a the livers with legical ten the off it is sure. At high on a gibbt hight during parties have so many



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here we made be errors in the reproduction. Mostly, hese errors were have been such that the new macro in here each that reproduce see and even only would have been dealeded. However, a few of the errors which have produced new macro indecides has were even better at reproducing hemselves. They would have therefore had an livant get and will that elevates to replace the original micro molecules. In this way a process of even then was a most thirteen the feet of more and more contiplicated seem production in the transmitted to the ease of the feet prior to elevate or and release to have in This gradually changed the atmosphere to the composition that this soular, and allowed the development of higher turns of the sach is finitely a mammals, and a time tely the hathat race.

This petute is a universe that star each fivery him in it is decised expenses a magnetise with all the observational expenses a magnetise with all the observational expenses a magnetise and cause one unanswered.

- I. Why was the early universe so hot?
- Why is the inverse so uniform on a large soor. Why does it work the sime and points of space and not and for aims. In portion are, why is the emperature of the matrix who has kigned directions nearly the same when we have not different recording it is a har two asking a nother it acadents an examinate on If they align occasing a nother it acadents an examinate mode it escribed above it there would not have non-time since the high langifier ghour ger from one its antiregion to another even though the regions were conscious there is a notice of a contract of a contract of the contract

happened to start out with the same temperature.

- Why did the universe start out with so nearly the critical rate of expans in that separates mode is that reconapse from those that given a textual to go forever, that even now ten thousand million years after it is still expanding at nearly the critical rate. If the rate of expans on one second after the big bang had been smaller by even one part in a hundred thousand implies in the universe who dibave reconapsed be true it ever reached its present size.
- 4 Despite the fact that the universe is so uniform and homogeneous characters sea et al contains on a stregularities such as stars and galaxies. These are thought to have level per from small differences in the lensity of the early universe from one regard to another. What was the origin of these density fluctuations?

The general theory of relativity on its own connot explain these features or at swer these questions because of its prediction to it the inverse's arted off with infinite density at the big bong's ngularity. At he wag larity, general relativity and all other physical laws would break town one couldn't profer what would come out of the singularity. As explained before, this means had one might as well out the big rang, and any exams before to out on the theory because they can have in effect on what we observe Space-time would have a boundary a beginning at the highling.

Science series is have uncovered a self aws that, within the limits ser by the uncertainty principle to this low the universe will develop with time of we know its state at any one time. These laws may have originally been decreed by Good but it appears that he has single efforted inverse to evolve according to them and does not now intervene on it. But he wild help hose the initials ale or coofiguration of the universe? What were the "hour fary conditions" at the beginning of time?



Companies on sweet sins as harters chose the self-at a distribution in the property of an amorphism the magnetic field in the property of an amorphism the magnetic field in the property of an amorphism the magnetic field in the property of an amorphism the magnetic field in the property of the control of the magnetic field in the magnetic field in the property of the control of the magnetic field in the field in the field in the magnetic field in the field in the field in the magnetic field in the field

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many universes, there will dig thably be some argentized shope where that started and in a smooth and an form manner from a fixed the will have the dig takes ha intering away in repeat it is as it what they write a like giringe but very recasionally highwre characterists will be giringe but very recasionally highwre characterists will be upon a both that we are leving in a region that that happens is a since to be amount and an form of Astronosyahi this in ghose in the construction. It because some simple in the leving one will be heavy out timbere hy happens were galaxies and stars from ed and were considered by the first for the consequence of a stars from ed and were considered by the first for the consequence of a stars from ed and were considered at the subsequence who were calculated asking the question who store in erse soon with This is no example. The applies on of which is known as the an brook principle which can be paraginated as two secretic and verse he way this because we exist.

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Interested to a new Marine for the court of the grade A terrace mare ner agreed as a hearth monart in a rein a trapolation of the Signatures, A transported Institute Before this a hit is a resetting en a lectures arme ice so mist people construction of the contract o se it access troose with their vertal are hits epect By your tarker sel in give to right in expect with A mention in the three was a vesting Resser American In I Legeller her tote in Marie Willespe a the 1 le with the labeles to pen not periods be as made it he bookers or so by to series rates a second to be single but a c the root line. Work, to also age to an iso interest or ske sy metry mis actaken be respective e proble to have quite prose a correct grove to be correct to come and constitutions break and sy try and a ry and but have reduced by I hope was there is a new magical handhe was of he with corse at ter du se it dister te salo a tra hace breker receitable as the said of the refer to a selection to be but her This the contract and the active described asserting to the I to ma I I sersee I will be a tree level a loss As a removed need twasta or mean and lower when two our south a sport was ent out to aske table of was rathe to a country for here was to flaw about he burbes reing tope of all the secret by the hell she to a situate hank gotten a remission and I can not a the paper In the last was the disc to all ake I he so era me taste

the Samer consorship which was not her very skill fact very quak with scientify papers. Instead I wrote a short paper with lan Mass the same routing in which we pointed out his problem with he half are and showed how it could be resorved.

The lay after I get back from Mone is I set out for I have phase where a way I e to receive a meril from the Frank of I string. My secretary budy Fe la had used her not no my lerable charm or ser smade british A rways to give herself and mottere se two notice as a plant y venture. However, I was held up in not way to the airport by heavy rain and I missed the plane. Nevertheless, I give to Philae Iphia in the end and received my notice. I was then sky too give a seminar on the inflammary in lerse at Dreve or very ying Philae Iphia. I gave the same seminar about the problems of the inflat many universe cust as in Misselfs.

A very some reflea to I miles was put orthonogeneous a few as this after his Paul Steinhard and Andreas Adre his of the construction. They are now a sen post are twith it is the what sea fed the new offat many mode," his education is to breaking it sometry. The illinitationary mode was to this man suggestion of fast symmetry breaking with the formation of both this

The new inflationary mode was a good after place of a nother security as the way it is. However, I all several their precise shower that at least in its original form it predicted his hyrearet value in some the temperature of the more wave background radiations after short work has also cast doubt in whether there can be a phase transit in in the very early at verse if he kind to provide the region approach, the new inflationary in well show and last a scient for the rivial hough a lot of people of in a see into have here if the charter and grapers as if it were all left hence in along colors the charter in flatamary model was put tinvariable line in the region has there is no phase tradition or a percise stag linstead there is may in the scheme one phase tradition or a percise stag linstead there is may in the line is the cause of quant in flat datams, which have large



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an serse bring an ead to be for mying miss of the possible his rices is nog give, but there is a particular in my of histories that are much note or the han he where These histories may be not red as bring and he surface in the earth with he distance from the North Note reprised ig mag havy time and the size of a circle if consent distance from the North Pole representing the small size of he an serie. The adverse's arts at the North Pole as a single print. As one moves south in the earth at the North Pole as a single print. As one moves south in the earth at the North Pole as a single print. As one

Pole get bigger corresponding to the universe exponding with maginary time. Fig. 8.4) The universe would reach a maximum size at the equator one would contract with increasing maginary time that single point at the Sciati Pole. Even though the aniverse would have zero size at the North and South Poles, these points will be not be singularities any more than the North and Sciati Poles on the conth are singular. The laws of science was board at the most as they do a the North and South Poles on the earth.

The history of the universe in real time, however where his very different. At about ten or twenty chousand in his overes, and two let have a minimum size which was eight at the sast ham radius of the history in imaginary time. At their recordings che an serie will expand the chair of offat onary mode proposes by Li, he but are would not now hove a assume hat the inverse wavereate is sometical in the right sort of state. The oniverse will be apart to a very large size. Fig. 8. I and eventually it would be appeared to a very large size. Fig. 8. I and eventually it would be appeared to be a very large level if we keep away from brack holes. Only it we could picture to an universe in terms of amaginary time would there he no singularities.

If the interese really is in such a counter stock there we are no singularities in the history of the universe in magnety time. It in an

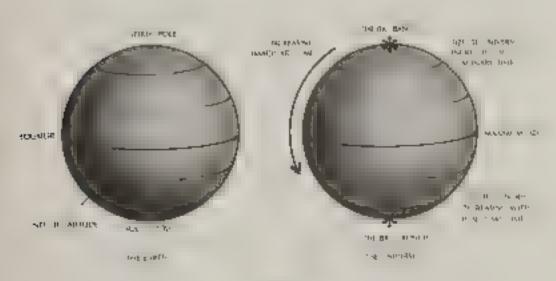


FIGURE 8.1

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This might suggest the hear of the souls of the property of the souther that we have really a shall all non the magnetic magnetic machines are the niverse has along the property of the three are the strength of the souther largest the three are the largest of hear largest the what we are the magnetic than a property the largest the what we also have a stap and that a property the ascence what we think he is increase to be at a compagn the approach I describe in Chapter I was a the bridgest star at the mark mode we have a conserve whether the second the mark the mode we have a conserve whether the second the mark the second the mark the mode we have a conserve which is the heart of the largest the second that it is meaningless to asker which is teal, reall or it against the model to make a transfer to that she may be seen, and the sample of the mark the second that the mark that the second the second that the second that the mark that the second that the second that the mark that the second that the seco

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affairs of the an verse. With the success of sole to the ones in describinglevents, most people have come as the seventhat Good allows the
universe to evolve according to a set of laws all these not intervene in
the universe to break these laws attowever the laws all not allowing
the universe should have intered like when it started into works at line
up to Good to wind up the classic rick and choose how rostart in off. So
ingles the universe had a beginning, we could suppose it had a creator.
But it the an verse is really completely self-contained that ingline
boundary or edge in would have neither beginning nor end it would
simply be What lake, then, for a creator?

## THE ARROW OF TIME

In previous hapters we have seen a wicur cours of the nature of time have covanged over the veses. Up to the beginning of this tent by adopte be eved to make after the That signs covered and a large way and all good make a cold by a number. Bed in medical and may elvey and all good make a solution of agree on the incenter a between two events. However the discovery that the speed of high mainteach the same to a cry passerver in matter how he wis loving led to the their heavy of readily and inhabit to have a shandon the are that there was a unique of the matter that continues the cach observer would have his low that are the mass result in as received by a clock that he cathod clocks carried by a foreign observer who measured the measured that there is a relative to the character who measured the measured that there is a relative to the character who measured the matter and a relative to the character who measured the matter and a relative to the character who measured the matter and a relative to the character who measured the matter and a relative to the character who measured the matter and a relative to the character who measured the same has a relative to the character who measured the matter and a relative to the character who measured the matter and the same has a relative to the character who measured the matter and the same and the same that the control of the character who measured the matter and the same that the control of the character and the same that the control of the character and the same that the control of the character and the same that the control of the character and the control of the character and the control of the character and the

And one treation by growty with quantum nechanics one had to treatice the idea of mag any time imaginary time is taken the shaply treating the middle of maginary formers ignored in maginary and the sught to be able to the round and go backward. This means

there in being important of therence between the terms, and back war I I rections of many time. On the other hand, when we look of that time there's a very got refere be seen he to be a and backwar I of records as we a I know. Where we this of france he is not the past on, the state come from the legal of we remember the past but not the future?

The away I science council string ash between he past are the to the More recises as explained earlier the two concernes who hopes an arithmetical particles to the ast only the mitror image so than the late interchanges. A content of the circumstance to the mitror of the circumstance of all particles on the running he mitror hackward. The two science has a rin the two material manual situations are not angental to the arithmetic of the mitror of he two operations. The particles of the circumstance of the mitror of he two operations as the Pop the rings of the series of while he is the same terms of abstance of another particles of while he is the same terms of another particles of while he is the same terms of another particles of another than matter.

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I complar at what s asos by given as to why we contist by ken a separation from her seeks together off the floor and no managers. It is the tible six at a six to the leading the second saw of therms.



aways in reases with the In other words, risk a form of Murphy's law in ngs a ways and to go wire go An oracle cup in the abie is a state of high infer but a broken cup on the floor is a user ered state. One ring trailing that the cup in the table in the past to the horizon and the floor in the fature, but not the other way thank

The crease of Islander creative, with time is me example of the signal area with the single are stongly shes the past of the foreign area of last three after a rooms to be histothere is the therm with incommon with the last three sides of entropy increases. It is not a sthe psychological across the last the contraction of the foreign to be a state of the pursues the lifection in which we remember the past such that the first the is the cosmological array of the last side in the first side of the pursue of the state of the state of the past such that the state of the cosmological array of the last side of the state of the past side of the state of

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consider the process of a psaw and hex. There is one are of the arrangement in which the introduces a carpone of the interest of the hand there are a very long on the arrangement of a will be pieces are loss of the arrangement of the area.

Special system stories of none of the small open of the average of the system will be a control of the average of the system will be an all softerest state to make it in the male of the period of the formal softerest state to make it in the area of the relationships of the system will be an all softerest states. This is the crisis of the area of the relationships of the system of the system

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Suppose however the oil near the afternoons held to she appear a state thigh or let be that it I not not exact a state to Area a time to universe see a probably he has a riber state. This who I wan that surject went for reasonable to a how we have ken compatitively himselves together and a place has a see his ken compatitively himselves together and a place has a horizontal to a horizontal has a probable for a see, at him in the notice that a see a see



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are so the street fere teres in last your remarker on the street fere teres in last your remarker on the street teres last fixe a superior with a surface of the last fixe a superior with a surface of the last fixe a surface of the last fixed last fixed the last fixed last fi

You can't have a safer bet than that

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In quantum theory of gravity as we was in the last of over in at least specify the state at the interse one who distributes a sweether as the past of the universe who the clear the past of the characters who the clear the past of some known and a treatment of the table of the boundary consideration they are force in extent and have the him of these coactes are greatly at the same case the region of time.



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## WORMHOLES AND TIME TRAVEL

The ast chapter docussed why we see the go it was why we remember the past but not the fat re. Time was treated as if it were a straight railway he in which one could only go one way or the other.

But what if the railway line had oups and branches so that a train could keep going forward but come brok to a same in that already passed? In other words, in ght it be possible for so needed to trave and the future or the past?

H. G. We is in The Time Machine explored these possistings as have countless other writers of science fiction. Yet many of the deas of science fiction, like submarines indicrave to the miles have become matters of science fact. So what are the prospects for time trave?

The first no cation if at the laws of physics might ready at two people to trave in time came in 1949 when Kurt (mile discovered it new space time a lowed by general relativity (för to was a marhematic an who was amous for proving that it is impossible in prove all true

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Counter to know about gettern the first when he and have seen, he is a rive in the lossature of A to be. So to infrincer in His source in the first in a property that the whole up verse was rotaling the neglect which he is a time term of he is a ring with respect to the rect aps that lattle tops or gyroscopes point in

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The or hard are are text of a protein between la protes and har her emorph density will be less that a substitute to be a conserved may an empty space for way come of a semisorie zero receive it may experience the space of ways or he are sufficiently less to be a constant to the configuration of the co

We show a experience of corresponds to the same pressure of the respective passage and had been recovered as the transfer passage as the transfer of the time to the recovered as the transfer of the time to the transfer of the time as the time transfer of the time transfer of the time as the time transfer of the time as the time transfer of the

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This is gho explain why we have not yet been exertal invited six from the factor at the will not avoid the probability of set and a large one were able to go back and change history buspose to revail the volument went were not killed a for great grant in her while he was stall a high There are many very one of this parameter but they are essentially contradictions about one were free to change the past

There seem to be two possible true and users the parallocations of the travel. One is all of the consistent histories approar. It save that even if space time is wirped at that it will be possible in true in other past, with happens in space time in the beautisticent spirituan of the location process. According to this seek to antique crade of go back in time an east story at weed that you have a ready arrived withe past and while there had not killed your great great grand a her or



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The test man some were historics does allow trace and the sax on a macroscopic scale. In Coapter 1 we saw that the localities are are unit impect by combinations of he operations C. P. and T. The effects that an analyzard cospiring when it is known as a total man, in a sign of trem. A to B. an also be sewed as an ordinary are less printing continues and incoming backward in time from less A. Since it an ordinary particle monitoring backward in time from less. A Since it and ordinary particle monitoring backward of the same is an interest and particle and that it is a hackward of the Ashas been toward. In this charter is Chapter 7, empty space is fined with pairs of virtual particle and air particles that appears gether these aparts are the come back together and annihilate each other.

with evan regard the pair of particles as a single particle is inglished as proposed to be When the pair is not not reward in time from the exertial which it approach that at which is annula at a single case of particle. But when he particle is travely has kind me on the eventual which the pair son his arest out that which is appeared to a single particle traveling to twant in time.

The explanation of how black holes can extraparticles and the area given in Chapter 1) was that one member of a sittander e and particle might. I have a back he camp he other member without a particle with which to annih like. The first ken particle might also to the hole as we that it is ght and escape from the sun my of the brack hele. If you to an observer a a chance it wast disposals to be a particle emitted by the brack —e

Income however have an iterent hole quital attent has present of the inechanism for emission from back he exponent of the votal pair that termine the back have trace the and particle as a particle trace inglockwarf of the country he hade. When it gets to the promator has the test to particle and article pair a horizontal resolution of the promator trace and the form the brook has been a few and excepting to in the brook has been to trace in the particle member of the virtual pair has believe to the content of the virtual pair has believe to the first content of the virtual pair has believe to the content of the virtual pair has believe to the content of the virtual pair has believe to the content of the virtual pair has believe to the content of the virtual pair has believe to the content of the virtual pair has believe to the content of the virtual pair has believe to the content of the virtual pair has believe to the content of the virtual pair has believe to the content of the virtual pair has believe to the content of the virtual pair has believe to the content of the virtual pair has believe to the content of the virtual pair has believe to the content of the virtual pair has believe to the content of the virtual pair has believe to the content of the virtual pair has believe to the pair that the virtual pair has believe to the pair that the virtual pair has believe to the pair that the virtual pair has believe to the pair that the virtual pair has believe to the pair that the virtual pair has believe to the pair that the virtual pair has believe to the pair that the virtual pair has believe to the pair that the virtual pair has believe to the pair that the virtual pair has believe to the pair that the virtual pair that the v

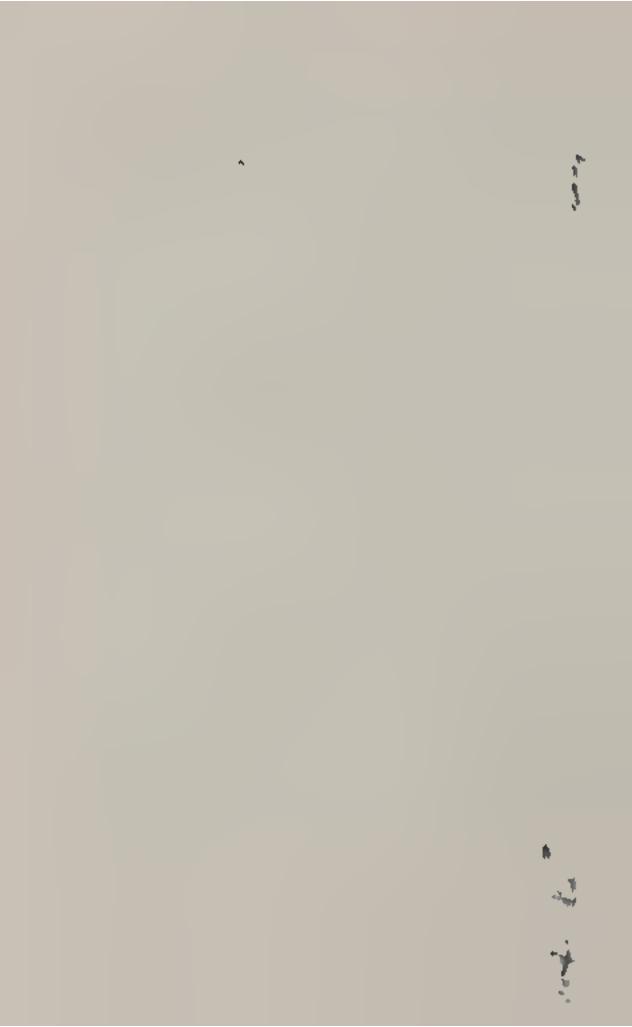


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# THE UNIFICATION OF PHYSICS

s was explained in the first chapter, it would be very econstruct a complete uniter the even everything in the universe at one go. So instead we have made progress by anding part a hear es that leser be a limited raig of happing as and by neglecting ether effects at approximating them by certain numbers. Then street for examine a leave as the contact the intractions of at any, without know give norma souchere contamismos as I constelle however one was a thope to that a complete a data entire theory the would nessure a these partial the rice as approximations, and Ture I not need to be a ljusted to fit he was by picka githe a least eterrain arbitrary numbers with theory I being est a risuch a hency s Robert as The anches with physics it insters spent miss of his rater years ans secessfully secretarny for anihed the evolution time was nour perfluce were mercultherings or gravity and the electric magnetic force but very little was known about the buclear forces. Moreover Einstell refused to becove in the reality of quarters inches is, despite the important to else had played in its devription. Ye it see is that porate this principle.

I la de lessen et prague en esta a le sar le m hither proposed we know so pith conducting it wise however shower of even a concept and beto As he my any tobascerus to a god a act . . . h. date exthiguns here nein to the tipert of the asmires bused as the concept for service at one strong home a type protection, dealer life the In genting spheres a National per May we to a greedy that the entry of the transfer is a two leaver near than the anar cast a leaver covers by Dracet here to be governed as the I was bought, Here the space open to the the consider parties and other than a little control to the reason phy a fasterer to agree the greater to the terms of the ter next of the Ken Ken but and a from task and his was leave e bereau promost recot as option on har a common new ne near the end of the search but the last to assess the are

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regarded as interent us needs tinge such superpart the "this world," as the steer and is with spire and with the force correctly particles at such a few with a particle parts of spire fund who if have neglected energy and so what can be a most cut the passive neglected energy and so what the control and that the passive neglected energy and so what the control and course to vide to make the infinites cancer and the control and energy read him, but who there is not error and there were any infinites left an anceped with subject to a control to the control and the transfer of the control and the contr

Despite these recipies are the achiever parties in he switer are to theories. I found seem to manch the observer particles most sen that the cound the select in the was probable the right answer to proble the nitrator if has a freezed the best way of I st graves with the other tres Hewever in 1 34 there was a re are ble change of a non-new reason was are called strong their nes In hose to mes the basic injects are not partilles, which occupy a single point it space by this i it have a lengt byt ne other mens in ke an horse thin price distring These strings may here with so care then strings or extras he is never with homselves not sed ups coses sings that I and Fig. 1. 2. A particle les les les point et space à éach distant à lime. Les us us every can here researe by all all space time the word he A st a methe whee has bout place or nispace at eith mome to st time So is history to some time is a way mensional surfact cared the work sheet. And with an such a wiele sheet can be described by two numbers in similarly by the time and the her the position of the print in the weige. The war I sheet of an i ien string is a step its



right of the raths through space time of the ends of the string tight. The weards contact actors which represents the proofer of the string at one particular time.

Two pieces of string can join together to the talking interest case of open strings they simply intractive coast Fig. 1.3 which the tase of closen strings it is the two legs in integral a particle rousers. Fig. 1.4. Similarly as ingle piece of string can invoke in the strings. In string theories, what were previously the light dias provides in the set are as well-extracting down he arising. Releases on a little particle is rough. It is emission on absorption of one periode by another corresponds in the fixiding or action ingregather is rough. For its please the gray tational force of the sum of the carrie was packed in particle.

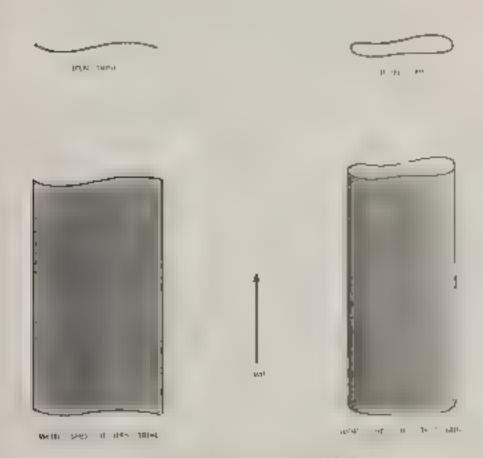


FIGURE ILLI AND FIGURE I. 2

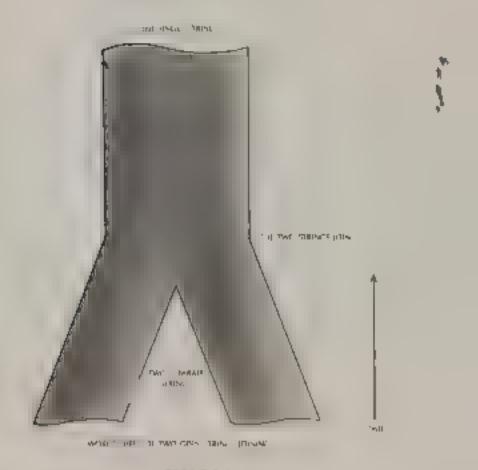


FIGURE 113

the surfaced to absorpt on by a particle in the earth it gill 50 line rong theory, this process corresponds to an History theory is earlier the plants of makes. The wo vertical safes of the Hicorrespond on the particles in the san and the earth is 1 he buttzontal erossbar correspond to the gray too the travels between them.

String theory has a curious history. It was ariginally invented in the are. Only an an attempt to find a theory to describe the six of to rec. The idea was that particles like the prison and the neutron discribed regarded as waves on a string. The strong frices are ween the particles would correspon to process of string that went between other bills of string as maspitier's web. For this theory to give the observed value of



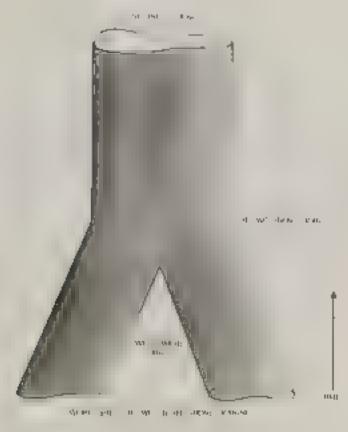


FIGURE 114

he string once between particles that a rings had to be like rabber bands with a pull of about ten togs.

I will scherk roto Person, com Schwarz from he to her last rate of decime gry published power towhich her stowed harst orgitheory of act ribe the grist about a toward mile of a min the simily were very more orgital about a toward mile of a min, or or I on molecular and monetons, with there are zeros a crit. The precisions of the string theory we no be use he stand as those of a need rotally tyling from a length scales for her was a term very small as meets less has a rhousant, in an mile man or offen me beach to a centimeter, centimeter on ordinal to the tirty his every a term. The last kills not receive miles ten in, owers it because a just about that the most people than doned the original soing the rivor the string for an axin of he

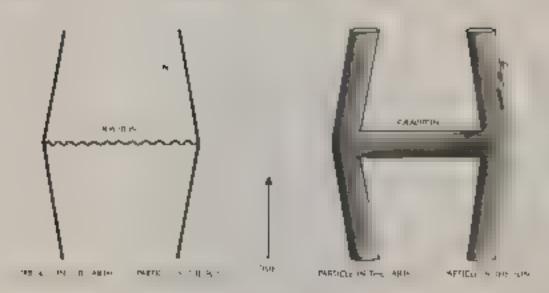


FIGURE 115 AND FIGURE 11.6

th ory based on quarks and givens, which see ned to be meen better with observations. Schenk it is, in tragic circumstances, he so terem from a abetes and went into a complianter in one was around to go eith nian in account insulin. So Schwarz was left alone as a manifold only supporter in string tierry, but now with the much higher proposed value of the string tension.

It 1984 in erest in strings and entry territed appareers for two reasons. One was the people were not ready making truch prigress oward showing hid so lengtavity was his continuous out dexplain the kinds of particles that we inserve. The other was he habit cation of a paper by John Schwarz and Make Green of Queen Mary College. London, that showed that string the my might be able to explain the existence of particles his have a built in a bundedness, we some of the particles that we observe. Whatever the reasons, a large in when if it explains to work it is string theory as I a new version was developed the so-called heteroic string which seemed as fit might be able to explain the types of particles that we observe.

String theories a so lead to infinitely, but it is thought they she a caree out in versions, we the hereing string though this is the verking though the significant knowledge bare a higger problem.



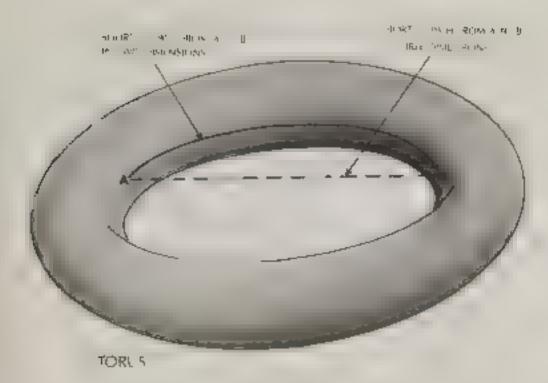


FIGURE 1..7

they sell the consistent only Espace time has either rener twenty six a mensions, instead of the result four. It course extra space time and delivary of each man, need if so ence betton in the land provide an delivary of each man, the normal restricts modigeneral relativity that one control to be faster than light or has a trained see Chapter. The deals of ske a shorter than light or has a trained see Chapter.

The deals of ske a shorter than light or has a trained see Chapter. The deals of the normal deals are the space well on has endorsing the result mensions and we carried aske the sortace of an another right of us long at 10 different and were on one side of the inside each of the right and you wanted to get to a point on the others delivation which is congressional die in accordance of the right however. You were abided to a notice that it is the measure of an eouth cut straight across.

We can writted at these extra dimensions. If they are really held what is we see only here space a measure and another time a measure of The suggestion is hat the other timensions are curved up to a space a crystim later something see any honder on million of the many and hafant of This sises a charge is displaned to

we've his a least a livery ace the six a sail t s a song that settle virtue to strate It so a hart court a unce to will me so as the hope of a win of the stranger than by the manufacts the length along he stead in a le win a regarding in his account to the trial which the and I state van and see he talk said he space it was the I make the new teams to a west a view terr of the fit of the the strate be a six this paid a contraction a scale in asthe same is high correct but in his cerson some business The treatment ment into his price simple specifical nows or wick he are teasures be extra filtern answer to be far Hismite I was too ship the his However traces o her organia W should not but not . I a he seems to cutled into a sill a litera mate a pathe cert cars on serve a l be cheered were has been very tree! Why I done to er in n pe the same terans affiner in whe he can a dimensions remain tightly curied ap?

I repossible a tracer with anthropic princip. The specific some least where the end of the end of the form the end of the

The cas has been answer more than he space made so not be a series of the parties of the between as a killer was to the effective of the same than the set of the first of the hand of the series of t



EWICHOLMENSIONAL ANIMAL

#### FIGURE 11.8

and so on. The significance of this is that the oral to of planets, like the earth, around the sun would be unstable the least disturbance from a circular orbit shelf, as would be caused by the gray that onal attraction of other planets, would result in the earth spiraling away from or into the sun. We would either freezoor be aurined up. In fact, the same behavior gravity with distince in more than three space dimensions means that he sun would not be able to exist in a stable size with pressure becausing gravity. It would either fall apart or it would not see its form a back hole. In either case, it would not se of much use its a source on heat and light for life on earth. On a smaller scale, the electrical proces that would the same way as gravitational forces. Thus the electrons would behave in the same way as gravitational forces. Thus the electrons would behave in the same way as gravitational forces. Thus the electrons would be the rescape from the alomal appether or would spiraling the nuties. In either case one could not have at one as we know them.

I seems contition for life, wear sinch on the another is regards they extrue much be seen in some another of the appeal to be well at repeat the present of the another of the appeal to be well at repeat the present of the another of the another of the such regions of the universe and a seems that of ends trong hours were the remarks. The theorem is a seems that of ends of the remarks of the re

Apother problem with there is a research forent single theories topen strings and bree a creat less lising a rising a million division which the extra a reason predated by strip theirs and weather a why show a point string hears and me knowledge regup be packed to be retired her some Income. and progress git begg I diwn I from him but he grestered e somer ig whit are old don as different str him signif offerent ways die tel give he extra mens as entil teach he same resils no out I neosie a Moreover as we as purities with one py using a wept distance and strings, which are next are were found to be other objects on I polyanics, which occupies two dimensional or upper inensional oil aics in some Appenies and he regarded as a thrane at takering as a thrane but there were like pranes for per to per a What this seems to maleate sit at there was sort of democra's among supers, asmy sing and pobra a theories, they seem to be a gether host more can be so it she more will be to than the rets. They as war to be after no a man man no to some I wamenta theory that are can tan I forest visit many

Per enhance searched on this uniterrying theory but when any success with a However the release the may no be any single technolation of the final and the factor of the final as (male who work on a last for multiple and anomaly interests at a single set of axis as Ing. I at

may be like maps—you can't use a single map to describe it is reface of the earth or an anchor ring iy is need at least two maps in the case of he earth and four for the anchor ring is cover every point. Facilities in which doney in a limited region, but different maps will have a region it werlap. The collection of maps provides a complete description of the surface. Similarly, in physics it may be necessary to use different formulations in different situations but two different formulations with a gree in situations where they can both be applied. The whole collection of different form dations could be regarded as a complete unified theory, though one that could not be expressed their main as single set of postulates.

But can there really be such a on field theory? Or are we perhaps just chasing a minage? There seem to be three possible uses.

- I There really is a commete an field theory or a concetter of over a sping formulations), which we will somer it is server it we are smart enough.
- There is no a timate theory of the a liverse, just an infinite sequence of theories that describe the universe more and a nore accurately.
- 5 There is not nearly of the universe even a carmot be predicted beyone a certain extent but occur in a random and arbitrary manner.

Some would argue for the third possibility on the grounds that it there were a complete serior aws, that would infringe God's freedom to change his mind and intervene in the world. It all this ke the operates can God make a stone so heavy that he can't that? By the dearthat God might want to change his minous an example to the falsely pointed our by St. A gustine of imagining God as a being existing in time time is a property on visithe an verse that God created Presumably he knew what he intended when he set it ap

With the accept of quantum mechanics, we have come to recognize

the events can be not be predicted with an open accuracy but that share is a ways a degree of uncertainty at stelling increase for the later begins the intervention of God but two able a very stronge kind of otherwise present on the event mention in a record ward any purpose in least 4 a were a war by refer to more the entire thy above by the change to god a securice cat and some first asserting as a transfer of the area of the prediction of the god as securice cat and some first asserting as a transfer of the area of the prediction of the god as securice cat and some first and the area of the predictions.

The second massing the later is an infinite sequence of more and more rish to the original agree of with a more experience so are to many occasions we have necessary to the sensing the later of the experience of the serving the later of the experience of the exper

However it seems to a grasery may provide with an error prive what is call the Planck energy for the form along the Creat

we be nineteen zeros. Is mass a ale he se in entraca i i the world it iself off from the real time universe. I form a line black he of Thus, how seem have reasonate of the animal pherenerges at here should have some in tasking to higher and pherenerges at here should be some a time the real the absorber (The surse the finek energy is a new long way the time energies of related the finek energy is a new long way the time energies of related the finek energy is a new long way the time energies of related the finek energy is a new long way the finek energies of related the finek energy is a new long that we approximate in the afformation the time which are the most that we approximate that gap with particle



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a ghair school, at has in the ne Welwholl them all octains shake some inverse or ing a thin, was had govern the armores and a cresponsible for our existence.

Even we do a survivor of a patenting on the entire this world not hear. that will dealer expeditivents, general topher reasons. The first is be limitation that the ancertally or to be by antimomechanges ets in acramaters of production. There are a give care and go around has I have a dever, this first limited in a restrict tive than the second nell processor in the attheway could raise a The Big 18 ms a time the its except except were smaple stout ins We cannot ever since exactly for the newson of three bodies in New apstherest charge in the later to ner as a settle nomber I wastes and the employers the heary. We are the notice laws that general election or of the rate of the but the mass after a one trens I are a lar we know the has a we that appear is a . enemis to an absorber by Notice are certain your rest to more subjects the state of some proble s we have as yet had larle success in pre-ching it in both vior from this bernalich equations. So even if we couldn't a complete select basic laws. Here we still be in the years a that eintel cerually a menging task learly ping better of the mar in perhaps, so hat we call make exetul predictions of the probable bate to a commented at the ista small es. A complete is assent an field the my sinn while best deal agricular a complete unuerstanding of the exerts are indies and a serioun existing

#### CHAPTER 12

### CONCLUSION

We find ourselves in a new yearing were. We want ry make sense of what we see around us and to lisk. What is the nature of the universe? What is our place in that I where did I are we different? Why is it the way it is?

Is try to inswer these quies a new we alopt some "world plot reust as an job are tower or total sices supporting a clifar ear has social
picture, so is the theory of superstrages. But are theories of the
universe, though the latter is much in the marke nature and precise
than the latter Both records lack inservational extreme into me has
ver seen a gian thate so with the earth on its mass but then looking
list scan a superstring either Hawayer, the time so herely to be the a
going scenetic theory because it gred ets that people so in dibe lote to
all off the edge of the world. This has not been found to agree a th
experience on essithat turns out to be the explanar in for the people.

A plane so prised to have disappeared in the Bermana Triangle.

The earliest theoretics, attempts in leser he and explaint the reservolved to a idea that events and hatturn phenomena were entired.

In spires with horse of the new hardere in a very humanlike and it presents are marker. They spires inhanted notice he are one regal kinds and in an area, in a display cross call unless, the the support notice. They are he proposed that their a are sight in order to ensure their in a dish, so another is a not be sensors time tally however times the element enhanthere were creating harders to so however times the element enhanthere were creating harders to so have stose in the most an set on he west of their remark say the harder market or the suggest for the sun he now it may the pariety to also precise paths a close to be treated to precise to he accurate the sun at the most inspired set and the great hist they were gones who obested streatings. Operate without a lex rot mis, it may account a stories is a like in the constant of the sun stories of the residence of the constant of

A first these regions are son blacks were in a son a nester of and and a term here a consider where is considered and arthursty to be ast 300 years more. The subspicious example of the segmn of the entered here are typically a second a learning of the entered here are typically a second a learning of the entered here and the a set of least that will do not be suggeted at there was the a set of least that will do not be the most for a series precially a entered here and the entered here are the entered and the entered here.

have the was should be dissent and a little of specify the initial ambiguration of a majorise Transport of the control of the world choose have the universe brigan and what have the level by the wind not district on the whiterse incention a protect first energy that a method first energy that an even his any scene of the protect of a second standard standard.

We now know that Laplace's hopes of determinish connect be realized at least out a terms be had now, of The a wertain removingle against a mechanics of the estate of pairs of quantities, such as a mossion of all electrons parties of most both by produce that he can be december against an exception as the such as a solution of the electrons of the electrons.

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1 this beak I have got a proportion of the contract of the con gr. to two a to gra that about a large sca str. It FARTHER BE A PART PALOR OF THE OFF A PARTY The sadge appreciation as a transfer re a three expression surcharge growner that have green a to that I to gipt by the property locality of a t control of an aring a her era the restor to as a sol the foreign a state of first tells short partings the property and and his her aveller to harming ame and out at a mar ere recovered to most heart of the transfer the termination has a short to be at a rest moreon so to any in page of Raymore and the comment of the place These signatures we buse to special contract phase of The state of the region of the care and the so from a silk et and te got use sha as pened and how the universe began.

when we carried parting or care with a contract the contract of possible a later of any size of the contract o

an thic perfecting from innite four attensions state with an single rites of some laters. It the surface of the earth but with quite to mensions of the universe with a single science in the universe with as its arge science in the try and a shifter small countries with the papernry keight states and exenditions are neglected to a few many and another we observe but it the universe is completely self-contained with no standard exendition as or house at as a did in ple by described which are the interest that has recome in plant as in the right Constant results.

Instead occasion the question. How much board of find have to construct ng be a vertised. It the no be adultary proposal is correct be had a freedom a active wise not a cinit as. He was 4, of cause of the east to be treedom a active wise the reast to be tended to the freedom of the section of a first may of a character may be seen to the or a small or more of a character may be seen to the or a small or more of a unified the ries, such as the heteroic string beary that are set in as seen in fill a schedule of a restore of smarteres as a implicated as he as the nature of Crod.

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men a new hear a har assemble what he unlerse a thank the quest it was not be thereband to people whose has ness a annual make the parameters as a northern parameter as except up with the a Wance of seen in the cres In the agh epith century of I supports a considerable of the parameters.

field and discussed questions such as indithe any case have a begin in high However in the innerventh and wen leth continues, science became too technical and mathematical for the phose phores or anyone else except a few specialists. Philosophers related the scope other indicates so much that Wittgenstein he most fairly as philosopher of this century, said. "The solt formal gitass for philosophe is the analysis of anguage. What a comedown from the great in later of philosophy from Aristotle to Kant!

However if we do discover a complete theory, it is all in this be understandable in broad principle by everyone not the allow scientists. Then we shall all philosophers, scient six and host crumary police he are to take partitive as asson of the quest in it why it is the and the universe exist. If we find the answer to the it would be the animal of God.

### AIBERT EINSTEIN

Einstein's transection with the politics of the numero bomb is well known he signed the famous letter to President Franklin Roose in that persuaded the United States to take the idea seriously and he engaged in postwar efforts to prevent nuclear war. But these were not just the isome educations of a scientistic ranged into the world of politics. Einstein's fellows in fact, to use his own words a vided between politics and equations."

Einstein's ear est political activity cause during the Firs. World War, when he was a professor in Berlin. Seekened by what he saw as the waste of human lives, he became involved in antiwar demonstrations. His advocacy of civil disabellience and public encouragement of people to refuse conscription did little to endear him to his colleagues. Then, for owing the war, he is rected his efforts toward recognizing and mpriving international relations. This too did not make him pripalar and soon his politics were making it of ficult for him topy sit the United States, even to give fectures.

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## GALI\*LEO GALILEI

G a lea, per saps more than any other single person, was responsited for the bit of modern science. His renowned conflict with the Cathouc Church was central to his philosophy for Galilea was one of the first to argue that man could hope to understand how the work works, and increaver that we could go this by observing the reaworld.

Gall en had acceved Copernican theory which a rice namets orbited the analysis early on his it was only when he found the evidence needed to suplicing the area had be started to publicly support in He wrote about Copernicans theory in It is an in it the usual academic Larintonic soon his views became widely supported or taids the universities. This annuyed the Aristoic an professors, which an ted against him seeking to persuage the Catholic Church to ban Copernicanism

Gall on worr oil by this, traveled to Rome as peak to the ecclesiase to authorities. He argues that the Bible was not brended a leaf us mything about somethic hermes, and that it was usual to assome that, where he Bible conflicted with common sense it was doing all agricultations.

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# ISAAAC 'NEWTON

Isaac Newton was risk a pleasant than His relations with other academics were notoricus with a bain his ateriale spea embreded in teaters cosputes. For owing publication of *Principia Mathematica* sure is the most officer a book ever written in physics. New on half risen rapidly into public promitence. He was apprinted president of the Kovac Society and became the first scientist ever to be knighted.

Newton sound shed with the Astronomer Royal Libat Hamsteen who had care or provided Newton with much needed data at Prince plant twas now withholding in or that not. Newton wanted Newton world it also has he had be inseen appointed to the governing may of the Royal Observatory and then tried at force minedian put and it he witall Eventually he arranged for Flainsteen's work to be served and prepared for publication by Flainsteen's mental enemy and son! He level But humbles took the case to court and, in the nick of time with a tourt order preventing distribution of the sinen work. Newton wis increased and songer his distribution of the sinen work. Newton wis increased and songer his

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### GLOSSARY

Absorbte zero: The lowest possible tempera are a which substances contain no heat energy

Acceleration: The rate at which the speed of an object is changing

Anthropic principle. We see the universe the way it is because if it were different we would not be here to observe it.

Antiparticle Each type of matter particle has a corresponding antiparticle. When a particle children with an antiparticle, they about sale, leaving only energy

Atom: The paste to the or many marter made up of a tilly nucleus consisting of print as and neutronsy's producted by orbiting electrons.

Big bang. The ving garity at the aeginning of the an verse

Big cranch: The singularity at the end of the universe

Black hote: A region of space-time from which nothing, not even light can escape, because gravity is so strong

Casalate effects The at ractive pressure between two Hat paralle meta, places placed very near to each other playacouth. The pressure is due to a reduction in the usual number of virtual part, less in the spalle between the plates.

Chandrasekhar lim/ts. The maximum possible mass of a stable cost star above which it must collapse juto a banck have

Conservation of energy: The law of science that states that energy for its equ. va. on in mass, can neither be created nor desiroyed.

Coordinates: Numbers that specify the position of a point in space and time

Cosmological constitute A mathematica, device used by Emistern to give space-time an inbuilt tendency to expand

Cosmology: The study of the un verse as a whole

Dark matter: Matter in gataxies, closters, and possibly between a usters, that can not be observed latterly but can be detected by is gray to sona, effect. As much as 90 period of the mass of the universe may be in little to it. If dark master

Duality\* A correspondence between apparently a flerent, henries that read to the same physical results.

Einstein-Rosen bridge: A hin rube of space time loking wo black holes. 400 ice Wormhole.

Electric charge: A property of a particle by which it may repert in arreasty state particles that have a charge of arreast sons positel sign

Electromagnetic force: The force that arises between particles with electric charge the second strongest of the four fundamental torces.

Electron: A particle with negative electric charge that orbits the nucleus of an atom.

Electroweak unthration energy: The energy (around ,00 GeV, above which the distinction between the electromagnetic force and the weak force disappears

Elementary particle: A particle that it is betieved, cannot be subdivided.

Event: A point in space time specified by its time and place

Event horizon: The boundary of a mack hore

Exclusion principle: The idea that two identical spin-in particles cannot have swithin the imass set of the uncertainty principle both the same position and the same velocity.

Field: Something that exists throughout space and time, as apposed to a passicle that exists at only one point at a time.



Frequency: Fig. 5 wave the number of complete excites per second

Gamma rays: Electron agnetic rays of here short walrelength, produced at each activities decay in hy conscious or elementary particles.

General relativity, consteads theory based on the idea that he laws it is entry stated by the same for all observers, to dial or how they are staying at explains the content of gravity at terms of the curvature of a four a mensional space a me

Geodesic: The shortest for longest path between two points

Grand antification energy: The energy above which is beneved the clerific magnetic functionable force and strong force become aids ingo shable in meach other.

Grand unified theory (GCT). A theory which up has the electromagnetic strong, and weak forces.

Imaginary time. I'me measure I using imaginary in Thets

Light cone: A surface in space time that marks in the possible prections in 19th rays passing through a given event

Light-second (light-year): The distance traveled by light plane second eyear.

Magnetic field. The field responsible for magnetic forces, it will comparate latency with the entire field, or the electromagne is field.

Mass. The quarter of a body, its merrial in resistance to access uson

Microwave background radiation: The radia ion from the glowing the forter of early and the second will be greatly redishable that appears not as ight but as marriages ratio waves with a wavelength of a few ten melecular A stress CC BE, on page 145

Naked singularity. A spore-time singular is not surrounded by a mask soil

Neutrino: A extremely igh possibly massless partour har is after the inly by the weak force and gravity.

Neutrons An uncharged partie to years son as in the proton is such account a for ringh eard, the partie of in an atomic nucleus

Neutron star: A colle star is apported by the exclusion principle to balk on per vern neutrons.

No boundary condition. The idea that the an verse is for re-bull has no inunuary (in anaginary time).

Muclear fusion. The process by which swim icle collide and coaless of larger a single, heavier nucleus.

**Nucleus:** The central part of an atom consisting on a no principle new rolls held together by the strong force.

Particle accelerator. A much ne dust using a ectromagnets, con accentour or or or of a charged particles, giving them more energy.

Phases First a wave the past on in its evident a specified me a measure a whether displaced a crough, or somewhere in the week.

Photon: A quartum of 1gbt.

Planck's quantum principle: The meaither ghood and many gas a waves can be constend or absorbed on a ordinate qualities, whose energy open portional to their wavelength.

Positron: The (position) marginal potaparticle of the enter-

Primordia, back hole: A black hole create the the way early and terse

Proportionals X is not write to Y means has when Y is much plead by an number so is X. X as reversely proportional in Y recars has when Y is man piece by any number. Yes divine by the number.

Proton. A positive charged particle very similar ratheries has no bas as a second for roughly be the particles in he may ros of most along.

Pulsar: A rotating neutrons of particles is regular pulses of radio waves.

Quantum: The this salue can a which waves also be employed at a neighbor.

Quantum chromodynamics (QCD). The heavy harders, her heavers some of quarks and gluons.

Quantum mechanics: The theory levels bed to no Physics of an are no physical Heisenberg's uncertainty prompte.

Quark: A charged) elementary part in har rees to strong force Profession, neutrons are each composed of three quarks.

Radan A system as ag pulsed rallio waves littles insistion of opinions by



Treatmenting the limit is assess a single pulse or ready the approximation reflected back.

Radioactivity. The spontaneous bre across of the type in a limit of across of another

Refish ft. The seeing of 1gh from a war hat is moving, was to a us due to the Doppler effect.

Singularity: A proper in apage on a place the apage time curvature becomes softened

Singularity theorem: A theorem, has shows that alsingularity most exist under corrang creamstances. To interpret another than the an worse prove thave stained and a singularity.

Space-time: The time invensional space whose poer wall exerts in

Spallal dimensions Any in the three sumicinstens that are spacelike in that is, any except the time dimension.

Special relativity: Elisters has hareful in the accordance also discende should be he same for a following in the absence of gravitational phenomena.

Spectrum: 1 - In some requencies that make up a wave vehiclion of the sup s spectrum can be seen in a rainbow

Spin: An internal property of elementary has a cs. related to our notice of an enthe everyday concept of spin

Stationary state. The high similar changing with a sobere spinning at a contour rate is seat on, by because it make whether a law is not discours.

String theory: A theory of prosters of A to a particles are distributed as waves of strings, Strings, save long to but to lotter the results.

Strong force. The singless in the four force to be consistences and he shortest range of all. The since quarks together within protons an inequality one one one one one of the protons and neutrons together to form atoms.

Uncertainty principles. The plant ple formulated by lifesse of global are an new rate exactly success both the position and have only one in the execution and the exact value of knows the one the less aller are come at knows containing

No boundary condition. The idea that the an verse is fin to but has no inunuary (in anaginary time).

Muclear fusion. The process by which swim icle collide and coaless of larger a single, heavier nucleus.

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Uncertainty principles. The plant ple formulated by lifesse of global and an new refree exact variety or both the position and have only or a strong community or rately one knows the one the less all rate variety at knows contact.

Virtual particle. In quantum a rechards, a particle, has can never held rectivilities but whose existence does have measurable effects.

Wave/particle duality: The convent in quantum mechanics that there is no fishington between waves and particles particles may sometimes be avelone waves, and waves also particles.

Wavelength: For a wave, the fotable between two advaces, Fing is in two adjacent drests.

Weak force: The second weakest of he four function on a forces with a very short range, it affects all matter particles but not income carrying particles.

Weight. The large exerces on a body by a gravitations, fig. if a proportional that not the same as, its mass.

White dwarf. A stable cold star supported by the exclusion principle continuous between electrons,

Wormhole: A this was at space-time connecting ill stant regions of the universe. We in thotas might associate to parallel or haby an verses and much provide the possibility of time travel.

## ACKNOWLEDGMENTS

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Stephen Hawking

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Stephen Hawking, who was born in 1942 on the anniversary of Galileo's death, holds Isaac Newton's chair as Lucasian Professor of Mathematics at the University of Cambridge. Widely regarded as the most brilliant theoretical physicist since Einstein, he is also the author of Black Holes and Baby Universes, published in 1993, as well as numerous scientific papers and books.



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